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USING DIFFERENT TECHNOLOGIES
TO SOLVE
UNIQUE PRECISION CLEANING PROBLEMS

by

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INTRODUCTION

For years those industries requiring precision cleaning in their production operations had access to chemical solvents which, because of their extraordinary properties and when used with the appropriate process and equipment, would suffice to precision clean virtually everything requiring precision cleaning. Principle among these were 1,1,2-trichloro 1,2,2-trifluoroethane (CFC-113) and methyl chloroform (MCF). When the Montreal Protocol process identified these chemicals as ozone depleting chemicals (ODCs) and targeted them for complete phaseout, the industries requiring precision cleaning were challenged to develop and implement alternatives for CFC-113 and MCF.

Efforts began immediately and worldwide with a great deal of success. Through those efforts there are now an abundance of alternatives for virtually every precision cleaning requirement. This sounds very impressive, and it truly is. Initially it would appear that there should no longer be any difficulties replacing CFC-113 and MCF within the industries using those chemicals for precision cleaning. However, upon examination this is definitely not the case.

While it is true there are abundant alternatives, none of them are universal. For example, there is no substitute chemical that is a perfect replacement for either CFC-113 or MCF in all their applications. In addition, there are a variety of parameters associated with the alternatives that vary considerably among those alternatives. These include such things as environmental impact, cost, worker safety, flammability, storage lifetime, different levels of reactivity with different materials, and so on. To further compound the problem, these parameters vary in importance depending upon such things as the geographic area involved, type and nature of process requirements, and political concerns.

The challenge now is not to develop new alternatives; it is to find existing alternatives that may work for a given process and, then, to select the most appropriate one for adaptation. To do this, it must be recognized that an alternative is most likely not going to be a "drop-in" chemical substitute--it is more probably going to be an entirely new process! With this in mind, it is imperative that a current process using an ODC be well understood. This implies understanding the "purpose" for which the process exists, not just how the process, itself, works. Only when this has been accomplished can potential alternative processes be examined and the "best" one selected.

Once the preferred alternative is selected and ready to be tested and evaluated, it is critically important to understand that someone else perfected the alternative process for their specific needs and

situation. This means that the process will undoubtedly need to be tailored, or adapted, to the new requirements. It is also important to realize that with the number of variables involved in the typical precision cleaning process, nothing ever works the first time it is tried. It will require a few iterations to be successful; it is important to approach the effort with this thought in mind.

In a diversified industrial operation with a variety of precision cleaning requirements, it is quite probable that one alternative process cannot be adapted to fit every need. In precision cleaning, every different cleaning operation often presents a "unique cleaning problem" to be resolved. More than one alternate technology may be required to solve the variety of problems that will arise.

At the United States Air Force's Aerospace Guidance and Metrology Center, it has been necessary to select, adapt, and apply several different technologies to resolve some of the unique problems that have presented themselves in the Center's quest to totally eliminate its use of ODCs for general and precision cleaning.

BACKGROUND

The Aerospace Guidance and Metrology Center (Center) is located in the state of Ohio, USA, at the Newark Air Force Base. It is a repair center in the US Air Force Materiel Command.

One of the Center's primary missions is the repair of inertial guidance and navigation systems and components used by most missiles and aircraft in the US Air Force inventory. The inertial systems and components of several foreign countries are also repaired at the Center.

The Center's industrial operations are contained within one large building covering approximately fifteen acres (61 000 square metres). Within this building are a large number of smaller structures totalling over 200,000 square feet (18 600 square metres) of floor space. These structures have strictly controlled environments and contain a vast array of complex repair operations.

The sophisticated electromechanical devices that form the nucleus of inertial systems are extremely susceptible to minute contamination, both particulate and non-particulate residue. As a result, great care must be taken to assure a clean repair environment. Of course, during the repair process it is necessary to "precision" clean many of the parts being assembled.

The Center has historically used large quantities of CFC-113 for both

general and precision cleaning. Prior to 1988 the center used over 2,750,000 pounds (1 250 000 kilograms) of CFC-113 each year. Other solvents used at the Center for cleaning include MCF and trichloroethylene. While not an ODC, trichloroethylene is a particularly toxic chemical. The Center, in its efforts to find alternatives for ozone depleting solvents, has recognized that there are other solvents in use which it should be able to eliminate with the same alternatives. Consequently, though the attention is on ozone depleting solvents, alternatives are simultaneously being sought for many other solvents classified as hazardous at the Center.

AQUEOUS CLEANING TECHNOLOGY

When the Center began its quest for alternatives, it made a corporate decision to seek, as a first choice, a technology which would provide the most environmentally friendly solution and which would be the least likely to come under close scrutiny and regulation in the future from regulatory agencies in the United States. The technology that appeared to satisfy this requirement was based on water, i.e. aqueous cleaning technology. Several factors played a part in making this choice.

First, the Center had an abundant and inexpensive supply of water. Second, the various aqueous products, i.e. detergents and surfactants, available for use with aqueous processes were either non-toxic or very low in toxicity. Third, aqueous technology materials contained no ODCs. Fourth, aqueous technology materials did not have global warming potential. Fifth, the aqueous products were not classified as "volatile organic compounds" (VOCs). (VOCs are regulated air contaminants in the United States.) Sixth, the aqueous products could be selected to be biodegradable in the municipal waste water treatment plant servicing the Center. Seventh, the treatment of waste water streams for the removal of various types of contaminants was a proven, mature technology in its own right; this was important because it assured that, if it should become necessary, it would be possible to acquire existing pretreatment technology for the Center's waste water to remove any undesirable contaminants introduced from the Center's cleaning efforts before passing it to the local waste water treatment plant.

When the Center began working with its first aqueous process in 1987, nothing was known at the Center about precision cleaning with water based processes. It soon became evident that not much was known elsewhere, either. Many mistakes were made in those early days of trial and error, but the Center was dedicated to make the concept work. Each mistake or problem was addressed as it was discovered and solutions were found. Over the years that have passed from those

early beginnings to the present, the Center has evolved a very sophisticated understanding of aqueous processes and has perfected the technology until it now believes that the vast majority of its cleaning processes, both general and precision, can be converted to aqueous processes. To date, forty-three percent (43%) of the Center's solvent based cleaning processes have been converted to aqueous processes. By January 1, 1995 at least ninety-five percent (95%) will have been converted to aqueous processes.

The Center has installed seventeen aqueous "cleaning centers" throughout its production complex. These seventeen cleaning centers form the basis for the present cleaning process conversions and for all the future conversions to aqueous processes. Each aqueous cleaning center is equipped with a variety of devices. These devices vary from center to center depending upon the processes to be performed. The devices may include an ultrasonic cleaner, a spray booth, a "dish" washing machine, a vacuum oven, Class 100 laminar flow booths, and other miscellaneous items. Incorporated with these well known devices are some extremely important supporting systems. The Center has found these systems to

be critical to the use of aqueous processes for precision cleaning. The systems will be grouped into three categories for explanation, i.e. water supply, water heating, and compressed air drying:

1. Water Supply: The Center has found that the quality of the water used in aqueous cleaning processes for precision cleaning is very important in assuring consistency in spot free cleaning. Each cleaning center is supplied with high quality deionized water meeting the United States' American Society for Testing and Materials (ASTM) Type E2 classification. The water is constantly recirculated through the deionizing system until it is used in the cleaning center. This is done to assure consistency in the quality of the water and to prevent biological film buildup within the system. The deionized water enters the cleaning center with a nominal resistivity of 18 megohms and must meet a 15 megohm threshold for acceptance. As the water enters the cleaning center it is filtered through a 0.2 micrometre absolute filter to remove particulate.

2. Water Heating: The deionized water is heated before use by a point-of-use water heater designed for use with deionized water. With this type of water heater the water is heated as it is used. Since no holding or storage tank is required, there is no loss of the deionization that may occur when deionized hot water sits in a tank. The temperature of the water delivered to the process can be adjusted from 60°F (16°C) to 155°F (68°C) as determined necessary for a particular process.

3. Compressed Air Drying: Drying is an extremely critical operation in precision cleaning if "water spots" and recontamination with small particulate are to be avoided. Drying must occur quickly following the rinsing operation while the parts are still totally damp, and it must be very rapid. The Center accomplishes this in a preliminary drying process using compressed air as a drying medium. For its particular cleaning requirements, the Center has found that the most effective and efficient drying can be accomplished with a hand held blowing device using the compressed air. The blowing device has a specially designed nozzle which permits a technician to use compressed air at a gage pressure of 60 pounds per square inch (414 kilopascals) without any safety concerns relative to the pressure. The pressure and flow rate (approximately 18 cubic feet per minute (0.008 cubic metres per second)) of the air from the hand held device will dry moisture from parts at least as rapidly as CFC-113 will evaporate from the same parts when allowed to air dry in still air. The compressed air has several operations performed on it before it makes contact with the part being dried. It is filtered to remove oil and water until the mass fraction of oil and water is reduced to a level of no more than 0.003 parts per million and to remove particulate larger than 0.01 micrometres. The filtering system used will operate effectively up to gage pressures of 80 pounds per square inch (550 kilopascals) and an air flow rate of 150 cubic feet per minute (0.07 cubic metres per second). The air is passed through a static dissipating nuclear ionizing device containing the element Po 210. This ionizes the air to nullify any electrostatic charge that may be induced by the technician on the part being dried and, thereby, reduces the incidence of electrostatic attraction of particulate during the drying process. The Center's experience has been that the compressed air works fully as well for drying purposes without heating as it does with heating. As a result, the air is not heated prior to use.

Even with the knowledge and experience gained at the Center from the development and implementation of its aqueous processes, each new application must be carefully examined and tested. It is not unusual that a new application will require tailoring of the various parameters that are part of the aqueous cleaning process. These parameters include, but are not limited to, the type of detergent used, the temperature of the water and drying systems, the water quality, the length of the wash and rinse cycles, the agitation techniques used, the drying techniques used, and the design of the fixture holding the parts being cleaned. One example which illustrates the need for process tailoring concerns the cleaning of an assembly from a device referred to as a gyroscopic compass.

The inner housing assembly from the gyroscopic compass requires precision cleaning prior to repair and, again, prior to final assembly. The assembly consists of the beryllium inner housing of

the gyroscopic compass to which a stainless steel motor stator is attached with eight symmetrically placed "tacks" of epoxy. The epoxy is a Bacon Industries product identified as LCA4 and is used with an activator identified as BA5. When this assembly was examined as a candidate for an aqueous cleaning process, it appeared that a process typically used at the Center for beryllium and stainless steel would be acceptable. The process in question required the use of a detergent with the trade name "Versa Clean", ultrasonic wash and rinse cycle times of 3 minutes each, preliminary drying with compressed air and final drying in a vacuum oven for a minimum of one hour. The water temperature during the wash and rinse cycles was $145 \pm 5^{\circ}\text{F}$ ($63 \pm 3^{\circ}\text{C}$), and the vacuum oven was operated at a temperature of $150 \pm 5^{\circ}\text{F}$ ($66 \pm 3^{\circ}\text{C}$). During the evaluation of the assembly following its first cleaning with the proposed process, it was observed that some of the epoxy tacks had loosened. After a considerable amount of exasperating thought and testing, it was found that the problem was actually quite simple to solve. During the process of installing the motor stator to the inner housing, the epoxy is cured at 97°F (36°C) for 8 hours. Apparently, the glass transition temperature of the epoxy established during the epoxy curing process at 97°F (36°C) was such that the exposure of the assembly to temperatures in the range of 150°F (66°C) during cleaning caused the epoxy to fracture. The temperature of the water in the wash and rinse cycles and the temperature of the vacuum oven used in the final drying process were adjusted to $95 \pm 5^{\circ}\text{F}$ ($35 \pm 3^{\circ}\text{C}$). Following this process tailoring, the process worked perfectly.

The Center has had several aqueous processes in full operation for as long as four years. These processes are used as the only means for cleaning on various inertial system parts and assemblies. The various parts and assemblies consist of a variety of materials including jewels, various adhesives and plastics, copper, and alloys of iron, aluminum, and beryllium together with many other materials. Included in these assemblies are over thirty-two different precision instrument bearings (Reference 1). The Center also repairs a variety of electronic circuit cards; many of these are now being cleaned exclusively with an aqueous process to remove the mildly activated rosin (RMA) soldering flux used in the repair process and to generally clean the boards. A specific detergent is used in this process which has undergone extensive testing for its potential short and long term effects on the various metals used in circuit board construction (Reference 2).

The Center never adopts an alternative as a process substitute until it is fully convinced, based upon its testing and evaluation, that the alternative will provide the same quality in the final product as did the ODC based process it replaced. With this understood to be a prerequisite, the Center has made three specific observations from

its experiences with the substitution of alternatives:

Observation 1: The quality of the processes has never decreased; in fact, it usually increases. Two examples will be used to illustrate this observation:

Example 1: In the refurbishment processes for the thirty-two different types of precision bearings that the Center restores to original condition for reuse in the systems it repairs, the yield has increased for every bearing (Reference 1). The increase in yield has ranged between twenty-five percent (25%) and sixty-five percent (65%), depending upon the type of bearing. Furthermore, this application of aqueous processes was one of the first at the center and has been in place for over four years. Throughout that time, there has been absolutely no indication in the extensive reliability data the Center maintains on all the systems it repairs, that the long term usefulness of the refurbished bearings has been adversely affected by the use of aqueous processes.

Example 2: The yield from the repair process for a gyroscope consisting predominantly of beryllium increased by 1.5 percent (1.5%) when the ODC based cleaning processes were changed to aqueous processes. The aqueously cleaned gyroscopes have been in use in operating condition for over a year. A number of the gyroscopes, after months of actual operation, have been removed from their parent guidance sets and subjected to an extensive "postmortem" analysis. These preplanned analyses were conducted according to rigorous criteria under the supervision of a team consisting of both government and industry experts. Nothing was found in the postmortem analyses to indicate any adverse, long term effects that could be attributed to the aqueous cleaning processes used in the repair of the gyroscope.

Observation 2: There has been no increased process time following the substitution of an aqueous process for an ODC based process. In fact, the process times are usually reduced. Again, two examples will be used to illustrate this observation.

Example 1: When the cleaning of a gimbal ring used in one of the older aircraft inertial navigation systems repaired at the Center was converted to an aqueous process, the process time for cleaning the gimbal ring decreased by ninety-two percent (92%). The ODC based process for cleaning the gimbal rings was required to be performed manually, one ring at a time. The manual process required about 15 minutes per ring; the aqueous process that was developed permitted 24 rings at a time to be cleaned in 25 minutes. (The cleaning

results were also better with the aqueous process.)

Example 2: The total process time for the same gyroscope described in Example 2 of Observation 1 above decreased by 7.1 percent (7.1%) when the cleaning process was converted to an aqueous process. The 7.1 percent (7.1%) reduction in process time for this particular gyro is equivalent to approximately two workdays consisting of eight hours each..

Observation 3: The aqueous processes have been found to be much less expensive than the equivalent processes using ODC solvents. The total cost to convert all of the Center's processes which can be converted to aqueous processes (over ninety-five percent (95%) of the processes) will be approximately US\$ 1 400 000. The breakdown of this cost is as follows:

-Labor:	None (Used Current Employees)	
-Equipment:	US\$	900 000
-Facilities:	US\$	400 000
-Deionized Water:	US\$	100 000
--Total Investment at Completion:	US\$	1 400 000
-Recurring Annual Cost Estimate:	US\$	200 000

The reduction in use of just the solvent CFC-113 that has resulted from the present conversion of forty-three percent (43%) of the cleaning requirements to aqueous processes is equivalent to an annual reduction in cost to the Center of US\$ 1 800 000. This figure is based upon what the Center currently pays for CFC-113. Other cost avoidance the Center has not quantified includes such things as:

- Cost of methyl chloroform no longer used for cleaning.
- Discontinued use of motors on CFC-113 spray booth fans.
- Decreased hazardous waste disposal.

In addition to the three general observations discussed above, the Center believes that the total energy consumption for all of its aqueous processes will be no more than and, in fact, probably less than the energy that was used to maintain the ODC solvent based processes. The ODC solvent based system did, indeed, consume large quantities of energy in a variety of ways. Some of the ways are given here. Energy is used to provide the heating and cooling required in the large distillation system used at the Center to reprocess CFC-113 to virgin quality for reuse. Energy is consumed by the large motors on the two carbon vapor adsorption units used to recover ODC vapors from the exhaust air streams of the many ODC spray booths used at the Center.

The carbon vapor adsorption units run constantly throughout the year. The carbon vapor adsorption units use additional energy in the form of steam to purge the carbon beds of adsorbed solvent periodically. Energy is also consumed in the operation of the thirty sump pumps that return used CFC-113 to the distillation system and by the exhaust fans on the CFC-113 impingement spray booths.

Finally, the Center did not ignore the contents of its waste water and the impact those contents may have on the local municipal waste water treatment plant that services the Center. The Center knew the contaminants removed in the general and precision cleaning processes at the Center during the repair of inertial systems were quite small in quantity, and it was felt that both the quantity and the type of contaminants would ultimately not be a problem in the waste water. However, to be certain, it asked representatives of the Environmental Protection Agency of the State of Ohio, USA, to visit on multiple occasions to observe and comment on the waste streams of the processes that have been installed. The results of those visits have been that there are not enough contaminants of any kind being discharged into the waste water treatment plant of the local municipality to warrant any special concern or precaution. In addition, the Center had a study conducted to examine the detergents being used and the contaminants in the waste stream, both at the present time and as projected for the future, to determine if any pretreatment would be necessary in the future (Reference 3). The company that did the study worked closely with the local municipality in conducting their study and the conclusion was that there is no reason for concern if the implementation of aqueous processes at the Center proceeds as is planned. Even with this positive information, the Center remains alert to the condition of its process waste water to forestall any unexpected impact.

NON-AQUEOUS TECHNOLOGIES

While the Center was committed to making aqueous technology work in its processes, it realized and expected that there would be some cleaning requirements that could not be performed with water and detergent, even with the applied knowledge and experience gained at the Center. This was, in fact, the case. Several specific cleaning requirements have been found which have defied the application of the present capability of aqueous technology; more are expected as the aqueous process conversion nears completion. These unique requirements will be referred to as non-aqueous cleaning requirements in the remainder of the paper.

It is obvious that non-aqueous cleaning requirements require non-aqueous technologies. As was discussed earlier, the selection of potential alternatives must address the performance requirements of the process, worker safety and health, the environmental impact, and the cost. The

Center has investigated numerous non-aqueous cleaning technologies. From among these, four specific technologies have been identified which the Center feels are essential if it is to meet its non-aqueous cleaning requirements. Each of these technologies appears to meet the Center's performance requirements on the specific cleaning tasks they are being applied to. In addition, the chemicals that form the basis for these technologies have no ozone depleting potential and are either non-toxic or have very low toxicity concerns. These non-aqueous technologies are Alcohol, Methyl Siloxane, Perfluorocarbon, and Supercritical Fluids.

It is expected that these four technologies will provide a solution for the remaining non-aqueous cleaning requirements that may generate. However, each of the non-aqueous solutions has one or more major concerns that will come into play when trying to apply them to remaining non-aqueous cleaning requirements. These concerns include cost (US\$), whether or not the material used is regulated as a volatile organic compound (VOC) according to US government requirements, whether or not the material used has direct global warming potential (GWP), whether or not the material used is flammable or combustible, and whether or not the material is classified by the US government as requiring special disposal procedures after use. These concerns for each technology are shown in Table 1 with aqueous technology included for comparison. The concerns given are for the particular materials which will be used at the Center in non-aqueous technologies. These materials will be discussed in more detail in the remainder of the paper. When considering the cost, it is important to acknowledge that at the Center, the material in the aqueous, alcohol, methyl siloxane, and perfluorocarbon technologies, when used for cleaning, may be used for many cleaning operations before it must be replaced. After replacement in the actual process, the used alcohol, methyl siloxane, and perfluorocarbon materials may be economically recovered through distillation. The gases used in the supercritical fluid processes for the Center, i.e. carbon dioxide and ethane, are released directly to the atmosphere after use. In supercritical fluid cleaning processes larger than those intended for the Center, these gases may be economically captured and recycled. In Table 1 the US\$/kg figure given for aqueous technology represents the cost for a typical water and detergent solution at the manufacturer's recommended concentration.

ALCOHOL TECHNOLOGY

One of the non-aqueous cleaning requirements that surfaced at the Center was the cleaning of mildly activated rosin (RMA) flux residue following the installation of a very fragile "pigtail" wire in a gyroscope repaired by the Center for both the US Army and the US Navy. The pigtail wires, in this application, are a form of electrical conductor so designed that when attached between two points that experience minor

relative motions, the continuity of the circuit is maintained without contributing any significant restraints to the relative motion. Pigtail connections are made from the gyro case to the float to supply electrical circuit continuity for the pickoff coils, the torquer coils, and the spin motor. The pigtail wire has a maximum diameter of 0.001 inch (25.4 micrometres) and is 99.4 percent (99.4%) silver with a small amount of nickel and magnesium. The wire is coiled to form a small diameter (approximately 0.03 inch (762 micrometres)) spring that has the lowest spring rate possible.

This pigtail wire is so fragile that the surface tension of water distorts and deforms it. This simple fact makes it impossible to submit the assembly containing the pigtail to any form of aqueous cleaning. The existing process uses MCF to remove the flux and CFC-113 to rinse the assembly. The assembly is immersed in both the MCF and the CFC-113 in this process, but neither solvent causes any deformation of the pigtail.

The alternative cleaning process that has been found is a process using isopropyl alcohol. The isopropyl alcohol has a surface tension of 21.3 dynes per centimetre (21.3 millinewtons per metre) which is between the surface tension of CFC-113 (17.3 dynes per centimetre (17.3 millinewtons per metre)) and MCF (25.5 dynes per centimetre (25.5 millinewtons per metre)). Testing has shown that immersion in isopropyl alcohol during the cleaning process does not deform the pigtail. It also is a fact that isopropyl alcohol is an acceptable solvent for RMA flux. Another favorable aspect of using isopropyl alcohol for precision cleaning is that there is a considerable body of data from Europe on its use as a precision cleaning fluid including validation of compatibility with a variety of metals, plastics, and adhesives (References 4 and 5).

The primary concern (see Table 1) with the use of isopropyl alcohol is its flammability. Its flash point is 53°F (11.7°C). Other concerns are that it is considered a VOC and is subject to regulation and that it has to be disposed of with special procedures since it is a flammable liquid.

The Center is in the process of buying a cleaning system similar to the one in which the testing mentioned above was done (Reference 6). It is expected to be installed in January, 1994. This system has proven design features which meet the stringent requirements of the fire, safety, and environmental concerns of the US Air Force as interpreted by the Center's enforcement officials. The system is designed to clean with pure isopropyl alcohol with or without ultrasonics and, even though it contains a flammable liquid, the safety features and design of the system are such that it may be placed in a normal production area without requiring any additional precautions in electrical wiring or construction. Among the features of the system are a "concentrator" for

impurities in the alcohol bath and a "scrubber" for the exhaust air from the system. The concentrator constantly removes impurities from the alcohol bath and returns pure alcohol in the form of alcohol vapor to the vapor zone above the bath where it is condensed back into the bath. The water-based scrubber removes the alcohol vapors and, hence, the VOC emissions from the exhaust air stream from the process to the low level of less than 0.04 pound per hour (5 milligrams per second). The water from the scrubber with typical operation of the cleaning system will contain a mass fraction of alcohol less than 200 parts per million. Because of this low concentration, the current position of the Center is that the water from the scrubber may be discharged directly into the Center's waste water without pretreatment. Should, in the future, pretreatment be required, the waste water stream from the scrubber could be easily captured and appropriately processed.

Another difficult cleaning requirement at the Center is the removal of very viscous suspension and damping fluids from parts with complex geometry. Some of these fluids, such as polybromotrifluoroethylene, are very dense and difficult to remove with the Center's aqueous processes. Preliminary testing has shown that polybromotrifluoroethylene can easily be removed from some of the Center's more complex parts by the isopropyl alcohol cleaning process. If further testing is satisfactory, the alcohol system may be adapted to this cleaning operation. Some of the assemblies containing the dense fluids are very fragile in their construction. This fragility causes them to be very susceptible to damage from even minor agitation. When this combination of non-aqueous cleaning requirements is taken together, the advantages of alcohol cleaning become apparent.

METHYL SILOXANE TECHNOLOGY

One of the non-aqueous cleaning requirements at the Center is the removal of silicone based damping fluid, specifically phenylmethyl silicone, from the gyro parts in which it is used.

The Center is investigating the use of volatile methyl siloxane fluids as a medium for the removal of this material. These fluids have some attractive features (Reference 7) including their distinctive ability to remove phenylmethyl silicone. They also have some concerns in addition to the ones listed in Table 1. Preliminary evaluations have shown these materials to be compatible with the specific metals and other materials of the parts to be cleaned, but there are insufficient test results to make a conclusive decision on this issue. Also, there is a question of the stability of the fluids in actual use. These two concerns are being addressed through further testing at the Center.

One of these materials, OS-10 made by Dow Corning Corporation, has

been used quite successfully for certain cleaning operations in the same system being purchased by the Center for isopropyl alcohol cleaning. (OS-10 has a flash point of 30°F (-1°C) so it is quite flammable.) The new cleaning system will serve as a test-bed for the evaluation of some of the methyl siloxane fluids for other non-aqueous cleaning requirements at the Center. The fact that the methyl siloxanes may be de-listed as VOCs by the US Environmental Protection Agency in the near future is a positive factor for the fluids. Because of the VOC issue, it may be desirable to use them in place of alcohol if they demonstrate the same cleaning ability as alcohol and the same degree of compatibility with the materials being cleaned. On the other hand, the methyl siloxanes are currently much more expensive than isopropyl alcohol. These kinds of issues must be dealt with as the Center's experience with the two technologies evolves.

SUPER CRITICAL FLUID TECHNOLOGY

The very critical precision cleaning required in the repair of inertial navigation and guidance systems and a strong concern about the impending phaseout of ODCs, the primary cleaning solvents traditionally used for this purpose, stimulated the use of the Small Business Innovative Research program to assist in developing solutions. The Small Business Innovative Research program funding is made available to the US Department of Defense (DoD) by the US Congress as a mechanism to encourage small US businesses with knowledge and innovative technology to apply their capabilities to solve DoD problems and, in so doing, become a viable part of the US technology base. Two such Small Business Innovative Research projects were initiated in 1991 with the Aerospace Guidance and Metrology Center being the recipient of the deliverable technologies.

One of the projects dealt with perfluorocarbon technology and will be discussed in the next section of this paper. The other project dealt with the application of supercritical fluids technology to solve difficult cleaning problems in inertial components.

Supercritical fluids were not new, but the application of this technology to precision cleaning of inertial components was an unexplored concept when the Small Business Innovative Research project was begun (Reference 8). The company selected to do the project was the Phasex Corporation of Lawrence, Massachusetts, USA. The Phasex Corporation, while considered a small business, had considerable experience in the application of supercritical fluid concepts. The cleaning of complex parts using supercritical fluids is a direct outgrowth of their prior experience in fundamental and practical solubility phenomena and materials interactions.

TABLE 1

<u>Technology</u>	<u>US\$/kg</u>	<u>VOC?</u>	<u>Direct GWP?</u>	<u>Flammable/ Combustible</u>	<u>Special Disposal?</u>
Aqueous	0.22	No ₁	No	No	No ₄
Alcohol	3.31	Yes	No	Yes	Yes
Methyl Siloxanes	17.64	Yes ₂	No	Yes	Yes
Perfluorocarbons	37.48	No ₁	Yes	No	No
Supercritical Fluids					
Carbon Dioxide	0.13 (2.00) ₅	No ₁	Yes ₃	No	No
Ethane	3.97 (20.00) ₅	No ₁	No	Yes	No

- 1 By US Environmental Protection Agency definition.
- 2 An exemption as a VOC is under consideration by the United States Environmental Agency and is expected to be granted in the near future.
- 3 Carbon dioxide does have direct global warming potential, but the carbon dioxide gas available from the commercial market for industrial use is extracted from the waste streams of chemical manufacturing processes and coal burning power plants. As such, it is currently viewed in the United States as an acceptable emission from a "secondary" user's perspective.
- 4 While aqueous products, themselves, may require no special disposal procedures, the aqueous waste stream might. This would be dependent upon the nature and volume of the contaminants removed during the aqueous cleaning processes.
- 5 Total cost of the gas used in a typical application for one cleaning operation in the supercritical cleaning machine at the Center. This cost assumes the cleaning chamber is full of parts and all the gas is vented from the machine to the atmosphere. With larger supercritical fluid systems, it may be economical to recover and recycle the gas which could reduce this relative cost.

TABLE 1

One of the specific non-aqueous requirements that the Center worked with Phasex to resolve was the removal of phenylmethyl silicone oil from a particularly complicated assembly. The assembly in question was part of an accelerometer and consisted of a small housing made of aluminum containing a pendulum made of beryllium copper alloy, an iron core magnet, and pigtails made from predominantly silver ribbon. The pigtails are approximately one inch (2.5 centimetres) long and are 0.0003 inches (7.62 micrometres) thick by 0.004 inches (102 micrometres) wide. Portions of the assembly are attached using LCA4 epoxy with a BA5 activator. (Both LCA4 and BA5 are Bacon Industries products.) The phenylmethyl silicone oil is forced around these various assembly components during operation, and its removal during cleaning is complicated by the fact that the spacings between the various components are very small. There are also recessed spaces that are difficult to access. It is preferred to clean the assembly fully assembled. This is difficult to do even with the CFC-113 and impossible to do with an aqueous process.

The past experience of Phasex was a considerable asset in shortening the time it took the company to solve the problem. The solubility in supercritical fluids (SCFs) of silicone oils and siloxane polymers of various molecular weights was investigated by Phasex in the mid 1980s. During these studies it was shown that carbon dioxide was effective for dissolving these materials only up to limited molecular weights depending upon their specific chemical compositions and/or functionalities. Beyond these molecular weight levels, it was found that ethane more effectively dissolved the silicone oils and siloxanes up to molecular weights as high as 500 000.

When challenged with cleaning the accelerometer housing, Phasex considered both carbon dioxide and ethane as potential candidates for removing silicone oils with the SCF process. The molecular weight of the oil was unknown but the Center furnished the company a sample for solubility testing. Carbon dioxide was tested at temperatures of 140°F (60°C) and 176°F (80°C) and at various pressures ranging up to a gage pressure of 7500 pounds per square inch (51.7 megapascals). With carbon dioxide at a gage pressure of 7500 pounds per square inch (51.7 megapascals), only about sixty percent (60%) of the phenylmethyl silicone oil could be dissolved, even at a solvent-to-feed ratio of 2000:1. Based upon previous tests with dimethyl, phenylmethyl, and diphenyl silicone fluids, ethane was tested as a solvent. At a gage pressure of 6000 pounds per square inch (41.4 megapascals) and 176°F (80°C), a solvent-to-feed ratio of only 400:1 dissolved one hundred percent (100%) of the phenylmethyl silicone oil. Thus, ethane was the preferred supercritical solvent for removing this rather high molecular weight silicone oil from the accelerometer housing.

Extensive testing was done by Phasex (Reference 9) to validate the compatibility of carbon dioxide and ethane with the various materials of the special assemblies from which the Center had difficulty removing certain oils. The combination of Phasex's experience, the testing and investigation they did on the Small Business Innovative Research project, and their close collaboration with the Center's process experts has been incorporated into the design and construction of an SCF cleaning station. This cleaning station was installed at the Center in November, 1993 and operates on either carbon dioxide or ethane. It has a chamber 4 inches (10.16 centimetres) in diameter and 12 inches (30.48 centimetres) deep in which the parts to be cleaned are placed. The cleaning station is safe and easy to use and delivers a superb product.

It must be remembered that SCF technology has not yet been demonstrated to be a truly effective means of removing particulate. It is, however, excellent at removing oils and greases from certain parts and assemblies where the temperature and pressure of the process will cause no harm.

The SCF cleaning station is intended to solve specific problems. It is not intended to be used where other technologies can do an equal or better job faster and cheaper and with an acceptable environmental impact.

PERFLUOROCARBON TECHNOLOGY

The second Small Business Innovative Research project was initiated to develop a particulate removal capability equivalent to that of CFC-113 using perfluorocarbon technology. The company selected to do this was Entropic Systems Inc. of Winchester, Massachusetts, USA. Entropic Systems Inc., as was the case with the Phasex Corporation, had had considerable experience in their field of expertise, i.e. particulate removal with emphasis on the use of perfluorocarbons. In the Small Business Innovative Research project, Entropic Systems' challenge was to apply that knowledge and experience to certain critical requirements encountered by the Center in its repair of inertial systems and components. Considerable effort was expended by Entropic Systems in collaboration with Center personnel in testing and evaluating various processes and process parameters (Reference 9).

The results were extraordinary. Entropic Systems developed an ultrasonic process to remove particulate using a perfluorocarbon, such as perfluoroheptane (PF-5070 made by 3M Corp.), together with a fluorinated surfactant, such as purified Krytox 157FS (made by DuPont Corp.). This combination was very carefully tested and conclusively

shown to remove particulate as well as CFC-113; actually, it removed particulate much better than CFC-113.

The process has been incorporated into a cleaning station which will be delivered and put into operation at the Center in early 1994 (Reference 10). The cleaning station is designed to have extremely low emissions, on-line particle sensors and an ultra violet spectrophotometer to monitor cleaning in real time, and many other features to make it a valuable tool for very critical particulate removal requirements.

While the perfluorocarbons used in the process will easily remove fluorinated oils, they have little solvency for other organic contaminants. Consequently, for some applications, the cleaning station may be used as a final cleaning operation for the specific purpose of removing particulate where high quality particulate removal is necessary.

The Center is very much aware of the extremely high global warming potential of the perfluorocarbons and of the US Environmental Protection Agency's concern for their use. The Center shares that concern and will use the perfluorocarbon technology only where nothing else will achieve the desired particulate removal necessary to the functioning of certain very high precision inertial components. However, with prudent care and until something better is found, this technology offers an important contribution to the effort to totally eliminate dependence on ODCs where high precision particulate removal is required.

CONCLUSIONS

The challenge of substituting alternatives for the precision cleaning processes using ODCs for general and precision cleaning is not an easy one. The difficulty often lies in selecting the "best" technology from among the many available technologies that form the alternatives. The best technology depends upon many factors related to a particular industry's needs. Also, more than one "best" technology is often required to provide a complete solution to an industry's ODC elimination problems.

An important fact to keep in mind in this effort is that there have been many success stories around the world for ODC elimination. What is being done at the Aerospace Guidance and Metrology Center is just one of those success stories. For those who have not yet implemented alternatives for ODC processes, these success stories offer, through the sharing of information, the ability to move past many of the difficulties that those with the success stories had to overcome.

This has the potential to greatly expedite the selection of a "best" alternative and to do it at a reduced overall cost.

The discussion in this paper, of necessity, is extremely brief and does not address the considerable detail that has gone into the development, testing, and application of each of the technologies for the cleaning needs of the Aerospace Guidance and Metrology Center. However, anything that the Center has learned or done in this area in the past and what it will learn and do in the future will be freely shared with any interested organization. Upon request, the author will discuss how to obtain this information and how to arrange for a site visit to the Center, if one is desired.

The US Air Force, through its role as an affiliate member of the international organization known as the Industry Cooperative for Ozone Layer Protection (ICOLP), has committed to share the knowledge and experience it has gained in eliminating ODCs from its many diverse processes. The Aerospace Guidance and Metrology Center is proud to play a role in that commitment.

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Implementing Alternatives to Ozone Depleting Solvents
-Some Considerations-

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ABSTRACT

The Aerospace Guidance and Metrology Center located at Newark Air Force Base in the state of Ohio, U.S.A., repairs inertial navigation and guidance equipment for the United States Air Force. The Center repairs thousands of the delicate, sophisticated electromechanical devices each year. The critical tolerances of many of the moving parts and other considerations mandate extensive "precision" cleaning as well as general cleaning during the repair process. The principal solvents used for this cleaning are 1,1,2-Trichloro 1,2,2-trifluoroethane and 1,1,1-Trichloroethane. The Center has begun modifying its many cleaning processes to use known alternatives for these solvents. The Center has already converted several processes to deionized water and biodegradable detergents and has committed extensive internal resources to define and implement changes throughout its remaining processes. While this effort has not been easy, it has made visible some special considerations which will ease and expedite the transition in the future.

INTRODUCTION

The Aerospace Guidance and Metrology Center is located in the state of Ohio, U.S.A., at the Newark Air Force Base. It is a repair center in the U.S. Air Force Logistics Command.

The Center has two primary missions. The first is the repair of inertial guidance and navigation systems and components used by most missiles and aircraft in the U.S. Air Force inventory. The inertial systems and components of several foreign countries are also repaired at the Center. The second mission is the management of the U.S. Air Force Single Integrated Metrology and Calibration Program worldwide.

The Center is comprised of, for the most part, one large building covering approximately fifteen acres. Within this building are a large number of smaller structures totalling over 294,000 square feet of floor space. These structures have strictly controlled environments and contain a vast array of complex repair operations.

The sophisticated electromechanical devices that form the nucleus of inertial systems are extremely susceptible to minute contamination. Particles five microns or less in size can cause a system to fail. As a result, great care must be taken to assure a clean repair environment. Of course, during the repair process it is necessary to carefully clean the parts being assembled.

The Center's industrial processes require extensive use of solvents to meet these cleaning needs and for other specific purposes. Among the solvents used are CFC-113, specifically Freon 113, and 1,1,1-Trichloroethane. Freon 113, a chlorofluorocarbon (1,1,2-Trichloro 1,2,2-trifluoroethane) is a trademark of E.I. Du Pont Nemours and Co., Inc.

Once used, Freon 113, like many of the solvents, is considered a hazardous waste. The Center reprocesses most of the Freon 113 it uses to virgin quality through a sophisticated distillation system, but a significant portion is lost through evaporation and hazardous waste disposal. Historically, the Center has used over two million pounds of Freon 113 annually. Of this amount, over six hundred thousand pounds have been purchased to replace that which was lost.

Freon 113, in addition to being a hazardous waste, is a serious threat to the atmosphere. Its impact on the ozone layer has generated action to curb its production and use worldwide.

Freon 113 now costs the Center \$2.37 per pound (\$31.05 per gallon). This is 395% of the cost a year ago (\$0.60 per pound). In addition, the cost of recovery of vapors from the Center's industrial processes, the cost of hazardous waste disposal, and the cost of reprocessing used Freon 113 contribute to the total cost of its use. The cost of using Freon 113, the threat of even higher cost resulting from reduced availability in the future, and the environmental issues have caused the Center to take an aggressive role in finding alternatives for this and other hazardous solvents.

For the past three years, Center personnel have been engaged in an intensive evaluation of equipment, techniques, and processes to identify suitable alternatives for a variety of solvent uses. These solvent uses include, in addition to cleaning, leak testing and component cooling.

LEAK TESTING

Freon 113 is used in several processes at the Center as a "gross" leak checking medium. Assemblies which have been repaired and will subsequently be hermetically sealed with an inert gas internal to the assembly must be tested to assure the integrity of the external

shell, or case, of the assembly. One of the steps in doing this involves checking for the existence of gross leaks. To perform this check, the assembly is pressurized with inert gas and submerged in a tank containing Freon 113 or FC-77 Fluorinert Brand Electronics Liquid. (FC-77 is produced by 3M, St. Paul, Minnesota). The technician then watches for bubbles which indicate the presence and location of a leak.

After considerable experimentation, it was determined that the same quality of leak detecting ability, i.e. size and quantity of bubbles could be obtained using a mixture of surfactant and deionized water as the medium. The surfactant thus far found to be most effective for this purpose is Triton X-100 and the mixture strength is 0.2 percent. (Triton X-100 is manufactured by the Rohm and Hass Company, Philadelphia, PA.) After the assembly is removed from the tank, it is placed in a vacuum oven and thoroughly dried. The external surfaces of the assemblies which are currently leak checked do not require precision cleaning and, with the same frequency of change of the tank medium, the water and surfactant mixture results in no more surface contamination as a result of the dipping than does the Freon 113. Also, no corrosion has been noted as a result of this technique.

One leak checking process has been changed to use the water and surfactant mixture and is working very satisfactorily. The other processes are now being examined with the intent to change them in the near future.

COMPONENT COOLING

The Center repairs thousands of electronic circuit boards annually in addition to the repair of the extensive array of electronic test equipment used in its operations. One of the diagnostic techniques used to locate and identify faulty circuit components is thermal shock. This is typically done using an aerosol can of rapidly evaporating solvent. These aerosol cans of solvents are referred to generically as "freezing compounds". When the solvent evaporates, it quickly drops the temperature of the component upon which it was sprayed. Dichlorodifluoromethane (CFC-12) is one of the commonly used solvents for this purpose. These freezing compounds drop the temperature to approximately -60 degrees Fahrenheit.

The Center's engineers have tested a mechanical device using compressed air as an alternative in many situations for the solvent used to cool components. The device tested, called Component Cooler, was made by Exair Corporation, Cincinnati, Ohio. It uses a Vortex tube to produce cold air. At an input air pressure of 80 psig it will drop the output air temperature below -28 degrees Fahrenheit and the air pressure to approximately 2 psig. Testing to date indicates

that this temperature drop is sufficient to duplicate the vast majority of the faulty components identified with the freezing compounds. In addition, there is no measurable static charge resident in the discharged air. The freezing compound stream emitted from the plastic tube supplied with the cans has been found to have a consistent static charge ranging from 50 to 600 volts.

Battelle Memorial Institute, Columbus Operations, Columbus, Ohio will be conducting a thorough evaluation of the Component Cooler for use in diagnostic testing of electronic circuits on behalf of the U.S. Environmental Protection Agency during 1991. The testing will be done using the set up at the Center.

Another device being evaluated at the Center for use in component cooling for diagnostic testing purposes is made by the Brymill Corporation, Vernon, CT. It is named Cryogun and is a small hand held dewar containing liquid nitrogen. It is designed to give the technician complete and easy control over the discharge of a small stream of nitrogen through various nozzle arrangements. It has the advantage of being totally portable and convenient to use. It has the disadvantage at the present time of requiring very careful attention by the technician to avoid dropping the temperature to too low a value. It appears to have application for several non critical cooling processes at the Center, and, with some design changes, could have broad application. The discharged nitrogen gas from the Cryogun is also static free and has the additional advantage of being less hydrophylic than either the freezing compound or the air.

CLEANING

The Center's repair processes, as mentioned above, require extensive cleaning. The overwhelming majority of the Freon 113 and 1,1,1-Trichloroethane used at the Center is used in these cleaning activities. The solvents are used in a wide variety of different types of cleaning operations. These can be summarized as flushing, bench, vapor degreasing, ultrasonic, and impingement spray booth operations. Flushing operations involve the flowing of solvent through the assembly or system being cleaned for a defined period of time. Bench operations encompass all cleaning activities accomplished by a repair technician at a work station using solvent for spot cleaning.

The Center has done extensive work testing aqueous processes as alternatives for ozone depleting solvents in the critical, or precision, cleaning of metal parts and assemblies of various compositions. The term "precision" cleaning, as used at the Center, encompasses the removal of particles 10 microns or less in diameter, the preparation of surfaces for ensuing processes where the quality

of the ensuing process is dependent on the cleanliness of the surface, where wear between moving parts is a concern, and other special concerns involving "cleanliness".

This work has proven beyond any doubt that aqueous processes are, indeed, suitable for precision cleaning of parts and assemblies consisting of metals, epoxies, plastics, and other materials.

Many lessons were learned as a result of the thoroughness required to verify that the aqueous processes were suitable as substitutes for ozone depleting solvent based processes and, subsequently, "proving" to management that this was the case. These lessons have caused the Center to not only consider the use of aqueous processes as its principal alternative for ozone depleting solvents, but also to change the basic philosophy of cleaning in its operations.

Prior to the aqueous process investigation, each technician at the Center did his own cleaning for the parts he was working with in the area where he was doing the work. This included all precision cleaning as well as all non-precision, or general, cleaning. Over many years with hundreds of technicians performing their own cleaning, as many different cleaning "techniques" developed as there were technicians. Such a situation is extremely difficult to control for consistency and uniform quality.

Now the Center has adopted a new approach. Precision cleaning will be done in a central Precision Cleaning Center. Only general cleaning will be done in the various production areas. The Cleaning Center concept provides several positive improvements to the repair operations. Of course, since fewer areas will be involved, it minimizes the expense involved in providing the equipment and facilities required for converting to aqueous based precision cleaning. It was learned early in the Center's efforts that the aqueous process worked extremely well for precision cleaning, but only if the various elements in the entire process were closely controlled; the centralized Cleaning Center concept makes this much easier to monitor. Also significant is the fact that a very small number of people will be doing the cleaning. This permits a significantly higher degree of quality control in the operation; the cleaning is uniform and consistent. Long term benefits in the reliability of the repaired items are expected to result from this change in concept.

One Precision Cleaning Center has been put into operation and another is planned to go into operation in 1991. The Cleaning Center concept is still evolving and improvements are being added as they are developed.

The Cleaning Center is situated in an environment that is maintained to better than a Class 10,000 Clean Room particle count. (A Class 10,000 Clean Room is defined as having less than 10,000 particles which are 0.5 microns in diameter or larger per cubic foot.)

The flooring is an elevated platform composed of two foot square panels that are static electricity dissipative. The technicians wear static electricity dissipative shoes which are put on when entering the Cleaning Center and removed when leaving it. To qualify as static electricity dissipative, the floor and the shoes must have a resistance to ground in the range of 1 to 1,000 megohms. The combination of static dissipative flooring and shoes reduces the incidence of electrostatic charges on the technicians, and, as a result, the effect of electrostatic fields is reduced as a mechanism for recontaminating the parts which have been cleaned.

The Cleaning Center is supplied with deionized water for all of its cleaning operations. The deionized water is maintained to a minimum resistivity of 15 megohms. The quality of the water is critical to the process. The Center's research found that when the water fell below 10 megohms resistivity, the parts being cleaned showed signs of corrosion, stains, and tarnish. These problems were not exhibited when the water resistivity was above 10 megohms.

A low volume, rapid recovery hot water system heats the deionized water to 155 degrees Fahrenheit for use in the Cleaning Center. The water is filtered through 0.2 micron absolute filters before use.

The principal cleaning device in the Cleaning Center is a self contained cleaning system that cleans with ultrasonic energy using biodegradable detergents and water in a cylindrical cleaning chamber. The ultrasonic cleaning action is produced via cavitation by a cylindrical space-laminated magnetostrictive nickel design transducer which forms the cleaning chamber. The ultrasonic cleaner operates nominally at a frequency of 20 kHz with a uniform power intensity of 400 watts per gallon. The cylindrical cleaning chamber is 10 inches in diameter and 14 inches deep. Adjustable timers control wash and rinse cycles. A solution of pure water and detergent from one of two holding tanks is pumped into the cleaning chamber to begin the wash cycle. The solutions in the two holding tanks are continuously filtered through 0.5 micron absolute filters and are maintained at 160 degrees Fahrenheit. When the wash cycle is complete, the detergent and water are drained back to the holding tank. Deionized water is passed over the parts during the rinse cycle to flush away detergent and loosened particles. The ultrasonic action continues during the rinse cycle. (Two sources for ultrasonic cleaning equipment with these characteristics are Magnasonic Systems, Inc., Xenia, Ohio, U.S.A., and Friess Equipment, Inc., Akron, Ohio, U.S.A.)

An aqueous spray booth is also located in the Cleaning Center. It contains a reservoir of heated water and detergent solution. When used, the solution is passed through a 0.2 micron filter. After use, the solution is returned to the reservoir for reuse. The spray pressure is variable between 0 and 160 psig. After spraying with the solution of water and detergent, the technician can rinse with heated deionized water. The spray booth with specially designed nozzles permits precleaning of recessed screw holes and other irregularities in a part's geometry prior to final cleaning in the ultrasonic cleaning equipment.

The parts are removed from the cleaner and are placed in a Class 100 laminar flow booth. (Air through a Class 100 laminar flow booth has less than 100 particles 0.5 microns in diameter or larger per cubic foot.) In the laminar flow booth, the parts are blown dry with dry, heated nitrogen. The nitrogen is filtered through a 0.5 micron filter and passed through a nuclear ionizing element to neutralize any electrostatic charge in the nitrogen or on the surfaces it comes in contact with. The parts are then transferred to a vacuum oven where they are completely dried. The vacuum oven is operated at a nominal 160 degrees Fahrenheit and a vacuum of 30 inches of mercury. The drying time used for most parts is one hour. After drying, the parts are placed in a second Class 100 laminar flow booth where they are packaged.

The Center's evaluation of the aqueous process has demonstrated conclusively that with the proper quality of deionized rinse water, proper water temperature, proper filtering of rinse water and detergent solutions, proper timing of wash and rinse cycles, proper selection of detergent, and proper orientation and loading of parts in the ultrasonic cleaning chamber, no degradation, either chemical or metallurgical, results in either the near or long term.

Several ozone depleting solvent based cleaning processes for gyroscopes have been successfully changed to aqueous cleaning at the Center. The gyroscope parts cleaned with the aqueous process include gimbal rings, float shell halves, fill tubes, end bell covers, and gaskets. In addition, miniature precision instrument bearing assemblies from most of the inertial guidance and navigation systems repaired at the Center are now cleaned using the aqueous process. The various parts consist of copper, jewels, various epoxies and plastics, and alloys of iron, aluminum, and beryllium together with other materials.

CONSIDERATIONS

Finding alternatives to the use of ozone depleting solvents in the Center's processes has been difficult, getting the processes changed has been difficult, and the effort has been slow in evolving.

However, some considerations have surfaced along the way which are being exploited to permit the effort to gain momentum at the Center. Many aspects of these considerations should be applicable to any organization striving to implement alternatives to the use of ozone depleting solvents, especially in the area of cleaning. These considerations are broken into six categories: policy, qualification, documentation, adaptation of existing equipment, funding, and benefits.

1. Policy

It is absolutely imperative, if a wide spread implementation of alternatives is to succeed, for the top management of an organization to commit the resources and the personal interest required to make it happen. One of the requirements of this commitment is the establishment of a comprehensive policy for the organization which will act as a focal point for all subsequent actions.

The Aerospace Guidance and Metrology Center has adopted a policy for the elimination of ozone depleting solvents from its industrial processes. The Center's policy is a three phase plan. In the first phase, now completed, all of the processes using ozone depleting solvents were identified and qualified. During the second phase, the processes using ozone depleting solvents will be separated into two groups. The first group will include those processes for which alternatives have been identified, either for the process itself or for the ozone depleting solvents used within the process. The second group will include those processes for which an alternative has not yet been identified. This separation will be achieved by actually implementing alternatives, where possible, with the remaining processes forming the second group. This effort is to be completed by 1993. In the third phase, Department of Defense laboratory facilities and/or industry will be used to research and find alternatives for those processes in the second group where an alternative could not be identified. The third phase is to be completed in 1995.

The Center has committed considerable resources to carry out this policy. Teams composed of engineers, scientists, and technicians have completed surveys designed to obtain information about the Center's cleaning processes. This information includes the location of each process, the part or assembly being cleaned, the material involved, the solvent used, and much more. This information has been compiled in an extensive data base. The data base will allow the sorting of the data by various factors to make the search for, and

implementation of, alternatives easier and more efficient. Other teams are in the process of testing and evaluation necessary to extend the implementation of aqueous cleaning throughout the Center.

2. Qualification

One of the most necessary and critical factors leading to the successful implementation of an alternative to an existing, proven process is the qualification of the alternative. This was, and still is, the case in the Center's efforts to change its cleaning processes to aqueous cleaning to eliminate ozone depleting solvents.

Extensive proof was required at many levels of management that the parts being cleaned were in no way adversely affected, either metallurgically or chemically, by the process and that the resulting cleanliness was at least as good as that obtained using the ozone depleting solvent based processes. Obtaining satisfactory "proof" proved to be difficult.

While it was difficult to determine the chemical and metallurgical impact of an alternative process and compare it to the results of the solvent based process, it was possible using the normal methods available in a good physical science laboratory. The determination of the degree of cleanliness, however, was another matter entirely.

At the Center, various techniques were used to compare the cleanliness achieved in the alternate and in the existing processes. These techniques range from unaided visual inspections and subjective evaluations by technicians who through the years have developed a "feel" for the cleanliness of a part, to techniques involving microscopy, particle counters, and/or the results of functional tests. While the engineering community has, in general, been satisfied with the results of the cleanliness evaluations thus far conducted, the methods used and the subsequent results are still open to question and somewhat subjective.

Quantifying the degree of cleanliness is an extremely difficult task. There has been little done in the past several years to provide a basis of comparison when dealing with precision cleaned metal parts. Techniques such as electron microscopy are effective in qualifying the cleanliness of parts with small flat surfaces; however, even the effectiveness of this technique is often reduced because the point of measurement is removed from the process location. This means the cleaned item must be transported through various contaminating environments before the evaluation can take place.

The problem of comparing the cleaning effectiveness of alternatives is further compounded when the item being cleaned is composed of severe geometries such as dead end threaded holes, small diameter tubes, the inside surfaces of delicate pressure compensating bellows, the inner races and balls of miniature precision bearings and etc.

The Center is currently engaged in working out the final details of a statement of work with Battelle Memorial Institute, Columbus Operations, Columbus, Ohio, for a contract which is expected to resolve this difficulty. The contract should be let in late June or early July, 1991 and should be completed within the ensuing year. Under the contract, Battelle will adapt a process developed for another purpose to provide a means to compare one cleaning process to another with respect to the degree of cleanliness attained to an expected accuracy of over 99.9 percent. The Battelle method will introduce stable isotopes onto the surfaces of the parts to be cleaned. The isotopes will mirror the actual contaminant(s) to be removed in the cleaning process. The stable isotopes are not radioactive and will not require special handling. The measurements in the Battelle method will require only a precision balance, a gas chromatograph with mass spectrometer (GCMS), and standard absorption spectrometry equipment. In the event those items are not present in a facility using the method, the measurements could be made elsewhere without affecting the accuracy of the test. The stable isotopes are relatively inexpensive to acquire and pose no hazard other than the hazard of the base material, itself. If this technique proves to be as effective as preliminary discussions indicate, it may become the basis of a long needed standard for comparing cleaning mediums as well as cleaning equipment.

Another qualification issue being addressed by the Center concerns the potential for corrosion from residue following cleaning of mildly activated rosin (RMA) flux on surfaces which are subsequently covered with a protective coating.

For example in one of the Center's processes, aluminum covers for displacement gyros with a copper strip plated on their mating surfaces are soldered together using a 600 watt soldering iron. RMA flux is used in this operation, and flux residue is burned onto the aluminum in the vicinity of the soldered joint. The current cleaning process is to use isopropyl alcohol immediately after soldering to remove the flux residue. The unit is then subjected to a pressurized Freon 113 spray to rinse away any remaining residue. Following rinsing, the unit is painted with an epoxy based paint.

Center personnel have determined that MSI-7000, a biodegradable detergent developed by Magnasonic Systems, Inc., Xenia, Ohio, used at full strength removes the flux from the aluminum covers as well as isopropyl alcohol. Further, the Center's Physical Science Laboratory has verified that the surface cleaned with MSI-7000, with no further

treatment, results in paint adherence equivalent to the adherence of paint on the surface after the isopropyl alcohol and Freon 113 rinse procedure.

A contract is expected to be let in late June or early July, 1991 to Battelle Memorial Institute, Columbus Operations, Columbus, Ohio, for a study to be made of the corrosion potential of the unrinsed residue of MSI-7000 on various surfaces following surface treatment such as painting and, in the case of circuit boards, conformal coating. In other words, if the surface has RMA type flux wiped from it using full strength, undiluted MSI-7000, and then, without rinsing, the surface is painted, what corrosion may be expected over time? With the correct paint or conformal coating, there is evidence to indicate there will be no corrosion. The Battelle study will be thorough and will address aluminum and steel gyro casing materials and the metals common to circuit boards in conjunction with the particular paints and conformal coating materials used at the Aerospace Guidance and Metrology Center. The results of this study may provide the basis upon which many RMA flux residue removal processes at the Center will be changed.

3. Documentation

It is extremely important when implementing change to have complete and thorough documentation of all aspects of the proposed alternative. The importance of the documentation is proportional to the number of levels and the diversity of the engineering and management approval process.

The task of the engineers at the Center for documentation of ozone depleting alternatives is compounded by two facts. First, there are virtually thousands of parts and assemblies for which process alternatives must be individually justified. Second, each of the processes is part of some workload which is being performed for a "customer" located at some remote location in another state distant from Ohio. That customer's engineering and management community, in addition to the Center's engineering and management community, must be convinced to authorize the change.

Experience gained in the last three years has generated a generic "final project report" for use in the implementation approval process. The report is designed to address all areas of concern in an easy to reference format. It is also designed to reduce the burden of creative writing normally confronting the engineer in report writing. It is loaded on a computer in a template fashion with the portions that will be consistent with each report already in place. Also, maximum use of attachments will further reduce the generation process. For example, one of the attachments will be a bibliography of existing technical documents. If the report is

addressing the cleaning of a part made of beryllium and a previous study has been conducted which addressed the chemical and metallurgical effects of the same cleaning process on beryllium, the document in the bibliography attachment will be referenced. It is expected that this generic final project report will increase the output of the engineers and provide a consistent level of quality and completeness to the reports. The report format is simple to adjust and will permit change as required and experience dictates.

The subject headings in the generic final project report are as follows:

- Project Title
- Project Number
- Test Period
- Project Location
- Background
- System
- Scope of Project
- Cleanliness Evaluation Method
- Current Cleaning Process
- Composition of Test Items
- Contaminant Identification
- Detergent Selection
- Water Quality
- Cleaning Equipment
- Material Requirements
- Cleaning Procedure
- Component Degradation Evaluation
- Cleaning Evaluation and Results
- Recommendations

Attachments:

- List of reference documents
- Project specific documents

4. Adaptation of existing equipment

One of the questions that always arises in discussions about implementing process changes from solvent based cleaning to aqueous based cleaning concerns the expense of acquiring new equipment to make the process change possible. While some new equipment is undoubtedly going to be necessary, it should not need to be extensive.

Much of the equipment already in use for solvent based cleaning can be readily converted for use with aqueous based processes. This equipment includes vacuum ovens, laminar flow booths, spray booths,

and ultrasonic cleaners. The spray booths and ultrasonic cleaners will require some modifications, but those are easily designed and installed by a competent and innovative engineering/technician staff.

The Center's personnel have modified a limited number of spray booths and an ultrasonic cleaner to function with water and detergent. The costs were minimal and the results very satisfactory. It is expected that this modification process will be extensive in the future.

5. Funding

Often, the unavailability of "funding" is heard cited as a reason to procrastinate in the effort to eliminate ozone depleting solvents from a facility's industrial processes. However, the cost of CFC-113 and the definite future cessation of its production make procrastination unacceptable when survival of the facility is the issue.

The Center considers the implementation of alternatives for ozone depleting solvents in its processes to be imperative for its survival. In that context, it used "in house" resources in manpower and materials to support the effort. These resources, paid for by the Depot Maintenance Industrial Fund (DMIF), are devoted to production support in any case, and this effort is considered to be vital production support. All of the implementation effort has been in this category.

That is not to say, however, that other sources of funding have not been sought and used to expedite the process. Defense Environmental Restoration Account (DERA) funds were sought and acquired to purchase three ultrasonic cleaners of the type described in the section above titled CLEANING for use in the Center's two Cleaning Centers. It is important to note, however, that part of the justification that helped the Center to acquire that funding was the effort it had already expended in its own behalf.

DERA funding has also been acquired to fund the two pending contracts with Battelle Memorial Institute discussed above, i.e. the development of a quantitative measurement of cleanliness and a thorough study of the corrosive effects of residue following RMA flux removal on assemblies which are subsequently covered with a protective coating.

6. Benefits

Many positive benefits resulted from the change to aqueous cleaning. One of the benefits was that process time was reduced for cleaning the parts. For example, cleaning of the gimbal rings was a manual operation taking about 15 minutes per ring. The aqueous process cleans 24 rings in 25 minutes.

The cleanliness of the parts has been at least as good as, and in some cases better than, the results from the old solvent based processes for cleaning. For example, the yields from the process used to refurbish precision bearing assemblies have increased from 25% to 65% for every type of bearing after conversion to aqueous cleaning.

The processes changed to the aqueous cleaning process have already had a significant impact on the use of solvents at the Center. The consumption of Freon 113 has decreased by over 30 gallons per day, and the consumption of 1,1,1-Trichloroethane has decreased by over 25 gallons per day.

The conversion to aqueous cleaning has been embraced by the workforce and by management. Using hazardous solvents is tedious and potentially harmful. Both technicians and management view the changes to aqueous processes as a positive improvement because exposure to hazardous materials is reduced.

Part of the improvement described above generated from the simple fact that for the first time in a long time, scarce engineering resources were devoted to the process of cleaning. This is an additional benefit of making such a drastic change to the way business is done. Drastic changes in any large industry will invariably require significant engineering resources, and engineering talent applied to any process on a large scale should result in improvement in the process.

CONCLUSION

The efforts at the Aerospace Guidance and Metrology Center have shown that processes using ozone depleting solvents for cleaning and other processes can be changed. It is interesting to contemplate that the changes, when made, result in improvements in the processes, product yields, and labor time. This has, indeed, been the case at the Center.

While many of the considerations addressed by the Center are focused toward its specific processes and management requirements, they should be applicable in general to any industrial activity addressing the elimination of ozone depleting solvents from its operations.

A STUDY OF FREON VAPOR LOSS
BASED ON 1991 PURCHASES

by

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19960520 016

PURPOSE

The purpose of the study was to establish a baseline for CFC-113 emissions and other losses that result from maintenance operations at AGMC. A total of 314,000 lb of CFC-113 was purchased in FY-1991. A great deal of it is emitted to the atmosphere. There are a large number of individual CFC-113 emission point sources located throughout building 4. The most significant CFC-113 emission sources and other loss sources in Directorate of Maintenance activities are:

- A. Spraybooths
- B. Sumps
- C. Drums
- D. Open Containers
- E. Degreasers
- F. House Vacuum
- G. CFC-113 Truck
- H. CFC-113 Still

A. SPRAYBOOTHS: According to the Acurex Corporation study and MAEL(4) records, CFC-113 use in spraybooths account for 130,562 lb/yr. The spraybooths in this category are those not connected to carbon adsorption units. The exhaust duct carrying solvent vapor from the spraybooth located in the displacement gyro area was monitored for the quantity of CFC-113 vapor vented during normal operation. It was found that 63% of the CFC-113 used had

evaporated before it reached the sump. If this measurement is representative of other spraybooths, 42% of the purchased CFC-113 is evaporated through the system.

B. SUMP: The evaporation rate from a sump was determined at the Physical Science Laboratory by pouring a measured amount of CFC-113 into a sump and then measuring the amount of CFC-113 left after a 24 hour period. The rate of evaporation of CFC-113 was found to be 18% per 24 hour period. If the rate of evaporation is assumed to be uniform for all the sumps (40 sumps in the building), then one can divide the unevaporated CFC-113 by 0.82 and multiply the results by 0.18 to obtain the total amount of evaporation. The total CFC-113 evaporated from the sumps was then divided by the annual CFC-113 purchase to get percent evaporation. It was determined that 30% of the annual purchase is evaporated from the sumps.

C. DRUMS: Some CFC-113 used at AGMC is contaminated with solutions not compatible with the distillation system. This must be disposed of as hazardous waste. According to Environmental Management records, 31,847 lb of CFC-113 was sold to a contractor as hazardous waste last year. This accounts for 10% of the purchased CFC-113.

D. OPEN CONTAINERS: A survey was performed in Building 4 to determine the amount of CFC-113 lost from open container applications. Based on the survey, about 146,500 lb of CFC-113 is used annually. A rate of evaporation was determined by measuring evaporation from containers similar to those used in

the production areas. The rate of evaporation was determined to be 11%. Using this information, it can be shown that 5% of the purchased CFC-113 is lost from open containers annually.

E. DEGREASERS: A degreaser is designed to keep volatile organic compounds from escaping the equipment during use. The annual CFC-113 use in degreasers is estimated to be 159,500 lb. Assuming that the degreasers are used properly, only 1% of the actual CFC-113 used is evaporated while filling and emptying the tanks and inserting and removing parts. Based on this assumption, 1,595 lb/yr is evaporated, which is 1% of the annual CFC-113 purchased.

F. HOUSE VACUUM: The CFC-113 lost through the house vacuum system was investigated using Infrared Spectrometry. An assumption was made for the second and third shift operations, that the work load on those shifts was one third of that performed on the first shift. It was determined from the data gathered that the CFC-113 loss through the house vacuum system is approximately 14,000 lb/yr. Based on this calculation, 5% of the purchased CFC-113 is lost through the house vacuum system.

G. CFC-113 TRUCK: When filling the Virgin Tank from the CFC-113 truck about 2,000 lb/yr of vapor is retained in the truck. This loss is about 1% of the purchased CFC-113.

H. CFC-113 STILL: It has been determined that the distillation and holding tank at the still for CFC-113 are emitting about 2.5% of the total reclaimed CFC-113. This loss accounts for 4% of the evaporation of the purchased CFC-113.

CONCLUSIONS

The total account of CFC-113 lost from the point sources based on last year's purchases are as follows (see Figure 1):

A. Spraybooths	42%
B. Sumps	30%
C. Drums	10%
D. Open Containers	5%
E. Degreasers	1%
F. House Vacuum	5%
G. CFC-113 Truck	1%
H. CFC-113 Still	4%
I. Unaccounted loss	2%

FREON LOSSES

BASED ON 1991 PURCHASES

314,000 LBS = 100%

SUMPS 30%

DEGREASERS 1%

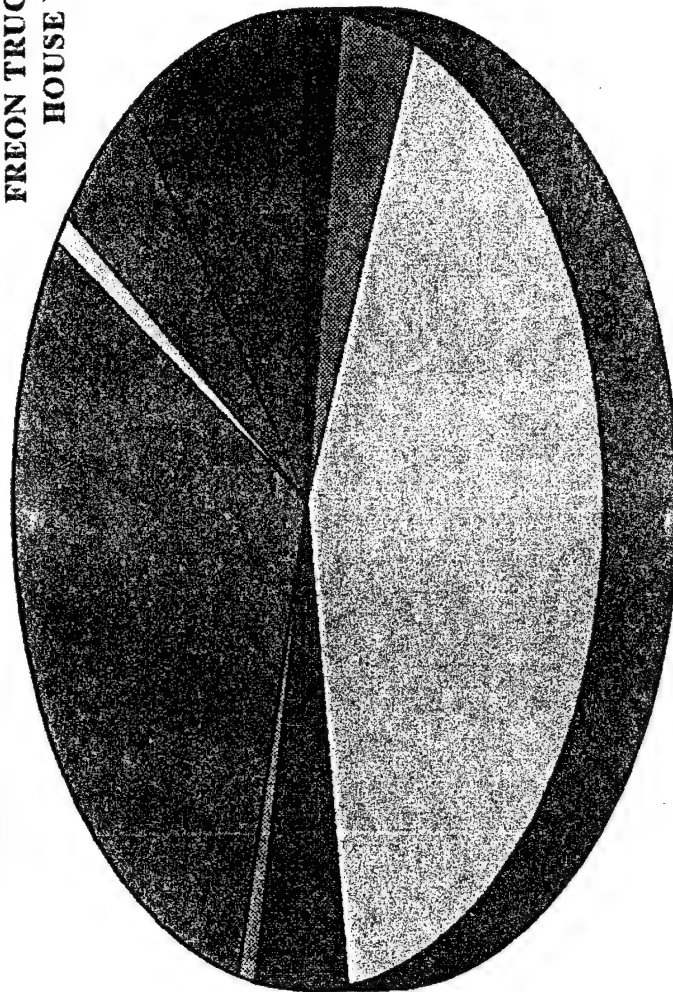
OPEN CONTAINERS 5%

FREON TRUCK 1%
HOUSE VAC 5%

DRUMS 10%

UNACCOUNTED 2%

FREON STILL 4%



SPRAYBOOTS 42%

**AQUEOUS ALTERNATIVES TO CFC-113 & MCF FOR
PRECISION CLEANING OF INERTIAL SYSTEMS & COMPONENTS**

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BACKGROUND

The Aerospace Guidance and Metrology Center is located in the state of Ohio, U.S.A., at the Newark Air Force Base. It is a repair center in the U.S. Air Force Logistics Command.

The Center has two primary missions. The first is the repair of inertial guidance and navigational systems and components used by most missiles and aircraft in the U.S. Air Force inventory. The inertial systems and components of other Department of Defense agencies and several foreign countries are also repaired at the Center. The second mission is the management of the U.S. Air Force Single Integrated Metrology and Calibration Program worldwide. The Center repairs thousands of delicate, sophisticated electromechanical devices each year. The critical tolerances of many of the moving parts and other considerations mandate extensive 'precision' cleaning as well as general cleaning during the repair process.

The sophisticated electromechanical devices that form the nucleus of the inertial systems are extremely susceptible to minute contamination. Particles of five microns or less in size can cause a system to fail. As a result, great care must be taken to assure a clean repair environment. Of course, during the repair process it is necessary to carefully clean the parts being assembled.

The Center's industrial processes require extensive use of solvents to meet these cleaning needs. Among the solvents used are CFC-113 and 1,1,1-Trichloroethane or Methylchloroform (MCF). CFC-113 is a chloroflourocarbon (1,1,2-Trichloro 1,2,2-Triflouroethane).

Historically, the Center has used over two million pounds of CFC-113 annually. Of this amount, over six hundred thousand pounds had to be purchased to replace that which was lost. Not all CFC-113 use is tied into closed-loop reclaimable systems. Therefore, CFC-113 lost to the atmosphere or sent off base as hazardous waste had to be replaced.

CFC-113, in addition to being a hazardous waste, is a serious threat to the atmosphere. Its impact on the ozone layer has generated action to curb its production and use worldwide.

CFC-113 now costs the Center \$2.40 per pound (\$31.44 per gallon). This is 400% of the cost just two years ago (\$0.60 per pound). In addition, the cost of recovery of vapors from the Center's industrial processes, the cost of hazardous waste disposal, and the cost of reprocessing used CFC-113 contribute to the total cost of its use. The cost of using CFC-113, the threat of even higher cost resulting from reduced availability in the future, and the environmental issues have caused the Center to take an aggressive role in finding alternatives for this and other hazardous solvents. For the past three years, Center personnel have been engaged in an intensive

evaluation of equipment, techniques, and processes to identify suitable alternatives for solvent uses.

CONCERNS

The Center's repair processes, as mentioned above, require extensive cleaning. The overwhelming majority of the CFC-113 and MCF used at the Center is used in these cleaning activities.

The Center has done extensive work testing aqueous processes as alternatives for ozone depleting solvents in the critical, or precision, cleaning of metal parts and assemblies of various compositions. The term 'precision' cleaning, as used at the Center, encompasses the removal of particles 10 microns or less in diameter, the preparation of surfaces for ensuing processes where the quality of the ensuing process is dependent on the cleanliness of the surface, where the wear between moving parts is a concern, and other special concerns involving 'cleanliness.' One of the most necessary and critical factors leading to the successful implementation of an alternative to an existing, proven process is the qualification of the alternative. This was, and still is, the case in the Center's efforts to change its cleaning processes to aqueous cleaning to eliminate ozone depleting solvents.

Extensive proof was required at many levels of management that the parts being cleaned were in no way adversely affected, either metallurgically or chemically, by the process and that the resulting cleanliness was at least as good as that obtained using the ozone depleting solvent based processes. Obtaining satisfactory 'proof' proved to be difficult. While it was difficult to determine the chemical and metallurgical impact of an alternative process and compare it to the results of the solvent based process, it was possible using the normal methods available in a good physical science laboratory. The determination of the degree of cleanliness, however, was another matter entirely. Currently, a unique method to determine the relative degree of cleanliness is being developed by the Battelle Memorial Institute, Columbus, Ohio - U.S.A. under contract for the Center. This method incorporates the use of stable isotopes to quantify the relative cleaning effectiveness of various cleaning processes and will be discussed later in this paper.

RESULTS

The Center's evaluation of the aqueous process has demonstrated conclusively that with the proper quality of deionized rinse water (15 megohm resistivity nominal - not to fall below 10 megohm), proper water temperature (nominally 155 degrees Fahrenheit), proper filtering of rinse water and detergent solutions (0.2 - 0.5 micron filters),

proper timing of wash and rinse cycles, proper selection of detergent, proper orientation and loading of parts in an ultrasonic cleaning chamber, and properly drying the parts after the cleaning process, no degradation, either chemical or metallurgical, results in either the near or long term. Several ozone depleting solvent based cleaning processes for inertial component parts and assemblies have been successfully changed to aqueous cleaning at the Center. The parts and assemblies cleaned with the aqueous process include gimbal rings, float shell halves, fill tubes, end bell covers, and gaskets. In addition, miniature precision instrument bearing assemblies from most of the inertial guidance and navigation systems repaired at the Center are now cleaned using the aqueous process. The various parts consist of copper, jewels, various epoxies and plastics, and alloys of iron, aluminum, and beryllium together with other materials.

Many aqueous cleaning processes are unique. The geometry of a part or assembly, the material it is made of, its sensitivity (i.e. fine coil windings or attachments), and the type of contamination require that the aqueous cleaning process for that part or assembly be specifically tailored to assure the desired level of cleanliness.

After an aqueous cleaning process has been developed and tailored, it is critical that all parameters verified in the testing phase be adhered. These include water quality, water temperature, detergent concentrations, cleaning and rinsing times, etc.. Failure to do so could result in poor cleaning results, damage to the parts or assemblies, or invalid data for quality control.

In all cases to date, aqueous cleaning processes have proved to be quicker, cleaner, and more cost effective than cleaning processes using CFC-113 and MCF.

CURRENT INITIATIVES

To permit the Center to meet required targets for eliminating ozone depleting and other hazardous solvents, as established by the "Montreal Protocol" international treaty and U.S. Air Force target goals, from its industrial processes, a formal, structured approach was adopted (see Appendix A). The approach provides the necessary guidelines for decision making and also provides streamlining and coordinating the Center's resources to achieve this goal. Under this structured approach, the Center envisions eliminating 90% of the 1990 level of solvent usage by December 31, 1993 - and the remaining 10% by June 1995. Although in its infancy, this structured approach has already gained corporate acceptance and cooperation and many new aqueous cleaning alternative efforts are underway.

As mentioned before, the Center has contracted the Battelle Memorial Institute of Columbus, Ohio to develop, validate, and document, a

stable-isotope-based cleaning performance evaluation method which can be used to quantify the relative cleaning effectiveness of various cleaning processes used to clean items composed of irregular or severe geometries. In order to assure reliability and maintainability levels are not degraded when ozone depleting solvents are phased out, a method is required to validate that the cleaning capability of the suggested alternative is at least as good as that of the existing, proven process. The methods commonly used by the Center to evaluate cleanliness include, but are not limited to, unaided visual examination, microscopic visual examination, solvent filtering with analysis of filter residue, and deionized water break test. However, these methods are not as effective as desired when the item being cleaned is composed of irregular or severe geometries as is the case in many of the parts and assemblies composing the precision inertial instruments repaired at the Center. Recent advances in analytical precision, coupled with stable isotope technology, offer a safe and potentially improved approach to measure the cleaning effectiveness. By identifying common contaminants, doping components under test with stable isotopes of these contaminants, and then measuring the effectiveness of various cleaning processes to remove these isotopes, a relative measure of cleaning process effectiveness can be established.

CONCLUSION

The Aerospace Guidance and Metrology Center has demonstrated the effectiveness of aqueous based cleaning processes and is continuing to develop other aqueous based cleaning processes with gratifying results. With proper attention to process parameters developed through careful testing and evaluation, the Center has concluded that inertial component parts and assemblies are effectively cleaned, with no resulting degradation, using the aqueous based processes. Also, faster cleaning times and better cleaning results are achieved over the traditional solvent based methods.

**THE DIRECTORATE OF MAINTENANCE
PLAN FOR ELIMINATING
OZONE DEPLETING SOLVENTS
FROM ITS INDUSTRIAL PROCESSES**

**Directorate of Maintenance
Aerospace Guidance & Metrology Center
Newark Air Force Base, Ohio
United States of America**

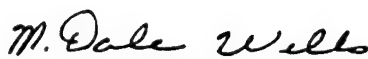
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The plan included herein is adopted and approved as of the date set forth below.


Corporate Concurrence:



GLENN P. CARTWRIGHT
Chief, Aircraft Product Division

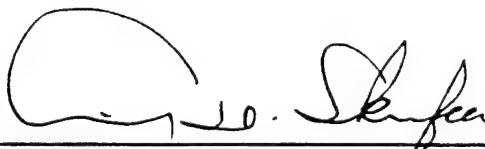


M. DALE WELLS
Chief, Engineering Division



WILLIAM J. PARKER
Missile Product Division

APPROVED BY:



ANTHONY D. SKUFCA
Director of Maintenance

DATE OF APPROVAL:

28 OCT 1991

BACKGROUND:

The industrial operations within the Directorate of Maintenance at the Aerospace Guidance and Metrology Center, (AGMC), Newark Air Force Base, Ohio, have historically consumed large quantities of Chloroflourocarbon (CFC)-113 (Freon 113) and 1,1,1 Trichloroethane. These two solvents have been classified as 'ozone depleting solvents' and, through the international 'Montreal Protocol' agreement, have been slated to be out of production and eliminated from use by, or before, the year 2000 in the case of CFC-113 and 2005 in the case of 1,1,1 Trichloroethane. The international community expects the current Montreal Protocol targets to be moved to 1995 and 2000 respectively.

Strong legislative actions have been taken to enforce the provisions of the Montreal Protocol and to encourage expeditious transitions to alternatives. These actions include a phased escalation of cost through imposed tax on the solvents at acquisition; emission control requirements that will be extraordinarily expensive to comply with; and criminal penalties for non-compliance that are severe, enforceable, and do not differentiate between Department of Defense personnel and civilian industry.

The Directorate of Maintenance purchased 430,000 pounds of CFC-113 in 1990 at a total cost of over \$960,000. By 1993 that same quantity of CFC-113 will cost over \$1,390,000. The \$1,390,000 does not include the exorbitant cost of forthcoming, imperative measures to control losses at all points of use.

The cost aspect of using the two solvents, the certain difficulty of acquiring adequate supplies in the future, and the impact continued use would have on AGMC's image and competitiveness in the future resulted in the Directorate of Maintenance taking aggressive action to find and implement alternatives. A program of experimentation to investigate the use of aqueous processes as alternatives to the use of CFC-113 and 1,1,1 Trichloroethane for cleaning inertial system parts and assemblies was initiated in 1987.

By 1988, the effort had born fruit. Several parts composed of different materials had been thoroughly tested in aqueous processes. The testing and evaluation process had been extensive and thorough. Through a carefully coordinated effort from beginning to end, the cleaning of these parts was completely converted from solvent to aqueous cleaning. This process and subsequent efforts have been carefully documented in various papers referenced in attachment 1.

Since that initial effort, other parts have been converted to aqueous cleaning. However, the total number of different parts now cleaned by aqueous based methods at AGMC are still only a minute fraction of the total number of parts cleaned with CFC-113 and 1,1,1 Trichloroethane.

During the intervening period from 1988 to now, considerable experience has been acquired at AGMC in the aqueous cleaning arena and the various parts cleaned have had the scrutiny of time. An aqueous 'Cleaning Center' has been constructed in the south end of Building 4 and is now serving as the production cleaning function for those parts converted to aqueous cleaning. Most of the equipment has been acquired and the Directorate is awaiting certification of funding for the construction of a second, larger Cleaning Center at the north end of Building 4.

The processes converted to aqueous cleaning have performed well beyond original expectations. The parts are being cleaned better and faster than they were previously. Also, absolutely no known degradation has been observed in any of the various parts and assemblies that can be attributed to the aqueous processes used to clean them.

The materials from which the various parts now cleaned on a production basis by the aqueous process are constructed include ferrous alloys, stainless steel, aluminum, beryllium, copper, gold, pivot jewels, and certain epoxies and non metallic substances. Certain Beryllium parts, while not yet cleaned on a production basis, have been thoroughly tested and have been found capable of being cleaned satisfactorily with an aqueous process.

Fundamental to the Directorate policy is the belief that a large majority of the Directorate's solvent based cleaning processes, be they general or precision in nature, can effectively be converted to aqueous processes. Those processes, including cleaning, which require an alternative other than an aqueous process will have to be addressed when, and as, identified. The alternatives for this category of processes will be sought from among those being developed throughout the industrialized world.

To permit the Directorate of Maintenance to meet required targets for eliminating ozone depleting and other hazardous solvents from its industrial processes, a formal, structured approach is deemed necessary. The structured approach or 'plan' must provide the necessary guidelines for decision making and provide for streamlining and coordinating the Center's resources to achieve such goals as shall be established.

That plan is set forth below.

THE DIRECTORATE OF MAINTENANCE PLAN TO ELIMINATE OZONE DEPLETING AND OTHER HAZARDOUS SOLVENTS FROM ITS INDUSTRIAL PROCESSES:

A Hazardous Solvent Alternatives Working Group (Working Group) is hereby created by the Directorate of Maintenance to consist of the Deputy Division Chiefs from each of the three Divisions that form the Directorate of Maintenance, i.e. the Aircraft Product Division (MAB), the Engineering Division (MAE), and the Missile Product Division (MAK). The Working Group will be chaired by the MAE Deputy and will have as ad hoc members, as a minimum, the MAE Division Chief, the Civil Engineering Facilities Branch Chief and the Environmental Management Chief. The ad hoc members will be available when needed to work issues in their respective areas of responsibility and expertise. The three Deputy Division Chiefs represent, and rightfully so, the corporate oversight for the respective Divisions' interests and, in that respect, the interest of the Director of Maintenance.

The purpose of the working Group is to provide the management direction, guidance, and oversight required to assure the Directorate of Maintenance will meet deadlines for phasing ozone depleting solvents out of its industrial process.

The Working Group is responsible for assuring that all actions in the effort to eliminate ozone depleting chemicals from Directorate of Maintenance processes will be initiated and/or reviewed and then concurred with unanimously by the Working Group before they are released as being completed and before they are implemented. (The initiation of an effort may take place, however, without the unanimous consent of the Working Group.) The Working Group has the latitude to establish its own procedures to assure it complies with its responsibilities.

The process of implementation from initiation into test to subsequent production aqueous cleaning for each and every part or assembly selected will be the joint responsibility of a team consisting of the following as a minimum:

Project Engineer/MAEL (team leader)
Product Engineer/MA_N
Process Engineer/MA_E
Training Leader or pertinent technician/MA_P

Of course, the Product Engineer, the Process Engineer, and the Training Leader or technician are to be from, or in support of, the production area responsible for the part or assembly in question. The product engineer, the process engineer, and the training leader/technician will not devote full time to the team effort; however, they will input to team decisions and will participate as required to do so. It will be the responsibility of the team to innovatively test and evaluate the part or assembly for both degradation and cleanliness and to perfect the process to obtain acceptable results. To assist them in discharging this responsibility are the following guidelines.

GUIDELINE 1: The final cleaning process accepted as a suitable alternative for an existing process shall result in no damage or degradation to the part or assembly being cleaned that will impact its function, and it shall render the part or assembly, as a minimum, as clean as the existing process as verified by the current methods employed for that purpose in the part or assembly's cost center.

This is a statement of final quality requirements. The words 'impact its function' are deliberate. Their purpose is to address and make acceptable the fact that any cleaning process does some 'damage' or 'degradation' to the item being cleaned, even if only a few atoms of the item's surface are removed. This guideline provides a working definition of the words damage and degradation for purposes of this effort by relating damage and degradation to 'function'.

There is a risk in employing Guideline 1. The risk is that a part may be 'damaged' unacceptably relative to function without being detected by the tests used to evaluate degradation.

A control for this risk is provided by the fact that the team members are the parties with fundamental responsibility for the item being cleaned and for the functionality of the final assembly of which it is a part. The team must unanimously agree on an approach and its results; if they cannot, the issue is elevated to the Working Group for resolution. The next higher review is the Division Chiefs and, finally the Director of Maintenance.

GUIDELINE 2: All solvent based cleaning processes with the possible exception of 'flushing' operations will be evaluated for conversion to an aqueous based process.

This guideline is an obvious assumption. Everyone knows that an aqueous process may not be a panacea for all processes. The guideline is important, however, because it sets the tone of the implementation process. It mandates the investigators set out to find the aqueous process that can work. It also provides the direction to be taken in planning for the equipment and facilities required for alternative processes.

GUIDELINE 3: It is preferable to assume some risk in part damage or some lost test time from contamination than it is to delay subsequent implementation through exercising excessive care at the beginning of testing; this is conditional upon the understanding that the cause of such damage or contamination is to be corrected through process adjustment before a final process is accepted for implementation.

This guideline provides a risk acceptance philosophy. It is based upon the fact that cost benefits to be obtained through ultimate implementation of process changes are very much greater than the small cost that may be incurred through the assumed risk, i.e. the savings in CFC-113 use and acquisition cost as opposed to the cost of a single part or assembly damaged during the implementation process.

GUIDELINE 4: If a part consists of one or more materials which have previously been subject to thorough degradation testing in a similar part or assembly relative to the aqueous process, and the results of that testing have been accepted as satisfactorily indicating no degradation concerns, that part may not be required to undergo any degradation testing on its own behalf; instead degradation testing may be inferred by reference. This decision will be made by the team assigned to that part.

GUIDELINE 5: Providing satisfactory degradation test results exist, if a part has been tested and evaluated for the degree of cleanliness achieved via a proposed aqueous process, and the results indicate the part is clean using the verification process for cleanliness established in the applicable Technical Order (T.O.) or shop practice, then further testing of any kind may not be required to justify converting the process from solvent based to aqueous based cleaning. This decision will be made by the team assigned to that part.

The purpose of Guidelines 4 and 5 is simply to permit expediting the flow from test initiation to process implementation. There is a risk involved in both guidelines. The risk is that an item may be damaged unacceptably in the case of Guideline 4 or will not be cleaned adequately in the case of Guideline 5. However, there are a number of controls which reduce the scope of this risk in addition to the conditional statement incorporated in Guideline 3 and in the explanation of that guideline. Those controls include the following:

1. The team members are the parties with fundamental responsibility for the item being cleaned and its functionality in the final assembly of which it is a part.
2. The team must unanimously agree on an approach and its results; if they can not, the issue is elevated to the Working Group for resolution. The next higher review is the Director of Maintenance.
3. Any observation at any time may cause the team to elect to do more thorough testing of any type; the guidelines do not prohibit more extensive testing, they merely give the basis to waive it initially in seemingly obvious situations.

The Working Group shall establish the priority of the items and existing processes to be subjected to the effort to find and implement an alternative.

Each item selected must have a thorough written report to justify process conversion. That report will be prepared by the Project Engineer from the Engineering Division. It must be concurred with, and signed accordingly, by all team members to be considered complete. The report must then be formally approved by the Working Group.

While each item selected must have a report written for that part, it will be acceptable to group items for inclusion in the report which are of like composition, which have the same Item Manager or technical order, and which have been proven to be cleanable with the same process.

Before an alternative process may be implemented, it is imperative that the request to do so must be approved via the appropriate Item Manager. In the case of the Oklahoma Air Logistics Center (OC-ALC), a single point of contact (POC) for all such ozone depleting solvent alternative requests was established in April, 1991. (This action was a result of the OC-ALC/AGMC Executive Conference held in April 1991.) Similar POC identifications will be solicited from the Sacramento Air Logistics Center (SM-ALC) and the Ogden Air Logistics Center (OO-ALC). All requests for permission to implement will be prepared by product engineering and forwarded to the Item Manager's POC through the AGMC POC. The AGMC POC will be the Hazardous Solvent Alternatives Project Engineer from the Engineering Division. The significance of the POCs in this effort is the ability they provide to work issues affecting Item Manager approval of process changes immediately, by phone, with priority attention and, thereby, to avoid administrative delays at both ends and delays through the mail system.

An alternative to the above process where, and if, it can be arranged, is for the item managers to delegate process approval authority for those processes which require ozone depleting or other hazardous solvents to AGMC's product engineers. If such arrangements are forthcoming, they will permit process change approval to be accomplished at AGMC.

The actual implementation will be done only after receipt of the Item Manager's approval or, in the case(s) where local approval authority is granted, after local product engineering approval. The formal implementation will then be initiated by a letter from the Working Group Chairman to the product engineering organization. Product engineering will provide the necessary documentation and approval authority to the appropriate production organization for implementation.

A team may evaluate more than one item at a time and there may be more than one team functioning.

All items which are converted to aqueous based cleaning must ultimately be built into a repaired component or system and sold via a full range of functional testing. This testing process provides a final level of control over risk. Further, the repaired components and systems are subject to the continuing scrutiny of the reliability data systems maintained by AGMC that monitor their performance in actual use.

In addition to alternate process development via an aqueous process, the Working Group will be responsible for the full gamut of issues which must be resolved and/or integrated to make it possible to phase out ozone depleting solvents from Directorate of Maintenance industrial processes within required time limits. These include, but are not limited to, such issues as seeking alternatives where an aqueous process for cleaning proves unacceptable, providing the planning for the facilities and equipment required to implement alternatives on a production basis, and developing comprehensive milestones for the effort.

Finally, this is a plan based upon need and experience. Need and experience are dynamic, and, hence, can change. Similarly, this plan may be changed to adapt if, and as, required through the corporate approval process.

The structure recommended above will permit decisive action by the evaluation teams while at the same time providing confidence that the final results will acceptably address everyone's concerns. This will enable the effort to gain and maintain momentum and, ultimately, to meet the Directorate of Maintenance policy targets for the removal of ozone depleting solvents from its industrial processes.

REFERENCES

Note: All of the references listed below were written at and are available from the Aerospace Guidance and Metrology Center, Newark AFB, Ohio; Phone (614) 522-7220, (DSN: 346-7220).

1. 'The Cyl-Sonic Cleaner: Aqueous Ultrasonic Cleaning Using Biodegradable Detergents' by Kenneth B. Patterson and Don E. Hunt; July 13, 1988.
2. 'Aqueous Cleaning of Instrumentation Bearing Assemblies' by Gene W. Ott; January 16, 1990.
3. 'Centralized Precision Cleaning of Inertial System Components with Aqueous Processes Improves Quality and Reduces Use of CFC's' by Don E. Hunt, Gene W. Ott, and Roger N. Johnson; April 3, 1990.
4. 'GIT-1-B SG and TG (Beryllium) End Housing Aqueous Cleaning Project Summary to Date' by Thomas L. Ciupak; July 5, 1990.
5. 'A U.S. Air Force Repair Center's Policy and Progress in Eliminating CFC's' by Don E. Hunt; September 17, 1990.
6. 'Implementing Alternatives to Ozone Depleting Solvents - Some Considerations' by Don E. Hunt; March 12, 1991.

Attachment 1

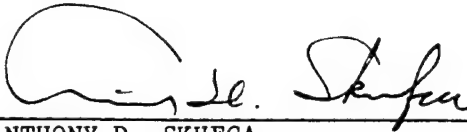
THE AEROSPACE GUIDANCE AND METROLOGY CENTER
POLICY
FOR THE ELIMINATION OF OZONE DEPLETING SOLVENTS
AND
REQUIREMENTS FOR ITS IMPLEMENTATION

Aerospace Guidance and Metrology Center
Newark Air Force Base, Ohio
United States of America

19960520 016

The policy and requirements included herein are adopted, approved, and in effect as of the date set forth below.


Corporate Concurrence:



ANTHONY D. SKUFCA
Director of Maintenance



DAVID R. BAKER
Director of Financial Management



STANLEY A. HUNT, Major, USAF
Director of Civil Engineering



SANDRA D. GATLIN, Major, USAF
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ROBERT C. COLSON
Office of Environmental Management

APPROVED BY:



JOSEPH M. RENAUD, Colonel, USAF
COMMANDER

DATE OF APPROVAL:

11 MAR 92

THE AEROSPACE GUIDANCE AND METROLOGY CENTER
POLICY
FOR THE ELIMINATION OF OZONE DEPLETING SOLVENTS
AND
REQUIREMENTS FOR ITS IMPLEMENTATION

PREFACE: This document sets forth the Aerospace Guidance and Metrology Center (AGMC) policy for eliminating ozone depleting solvents from its industrial operations and sets forth requirements for the policy's implementation.

INTRODUCTION: The critical tolerances of the inertial navigation and guidance equipment components repaired at AGMC mandate extensive "precision" cleaning during the repair process. As has been industry practice, various solvents have been historically used for this cleaning. Principle among these are Chlorofluorocarbon (CFC)-113 and 1,1,1-Trichloroethane. Both of these solvents have been classified as ozone depleting substances (ODSs) under the 1987 international treaty "Montreal Protocol on Substances that Deplete the Ozone Layer." Commonly known as the "Montreal Protocol," the treaty was ratified by the US Senate in December 1988. The Environmental Protection Agency (EPA) has since developed domestic regulations to insure the reduction and eventual elimination of the production and use of various ozone depleting substances. Air Force Regulation (AFR) 19-15 implements Department of Defense (DoD) Directive 6050.9 and directs compliance with the Clean Air Act Amendments of 1990 and EPA regulations relating to CFCs, halons, and other ozone depleting substances.

The President, in the 11 February 1992 news release, announced that the United States would unilaterally accelerate the phaseout of substances that deplete the Earth's ozone layer. He stated that, with very limited exceptions, the US would eliminate all production of substances that deplete the Earth's ozone layer by 31 December 1995. To accelerate the process in the near term, the President called upon US producers to reduce production of these substances to 50 percent of 1986 levels by the end of 1992.

These and other national and international initiatives underway mandate a rapid termination of dependency on ozone depleting solvents in AGMC's industrial activities. Based on this direction, the AGMC Commander has initiated a policy to achieve total elimination of the solvents classified as ozone depleting substances from AGMC's industrial processes by the end of calendar year 1994.

POLICY: The AGMC policy consists of two phases and is as follows:

Phase 1: Eliminate a minimum of 90 percent of the 1990 use of ozone depleting solvents by 31 December 1993. This is to be achieved through substitution of acceptable alternative processes and/or through the changing of existing procedures.

Phase 2: Eliminate the remaining 10 percent or less of ozone depleting solvents by 31 December 1994. This is to be done by using Department of Defense and private sector resources to identify solutions to difficult-to-resolve uses of ozone depleting solvents. (This effort will be ongoing throughout the policy period.)

REQUIREMENTS FOR POLICY IMPLEMENTATION:

1. Ongoing efforts at AGMC have indicated that aqueous cleaning processes can be developed as alternatives for the majority of AGMC's current ozone depleting solvent based cleaning processes. In order to achieve the portion of the targets set forth in the above policy that can be achieved through conversion to aqueous processes, it is imperative that extensive alternative processes development take place and that adequate capability for aqueous cleaning be in place early in calendar year 1993 to accommodate the new processes. Adequate capability has tentatively been judged to be between 12 and 27 cleaning centers distributed throughout the Directorate of Maintenance production complex. (Twelve should be considered the absolute minimum; the final number will probably be closer to 16 with 27 being the absolute upper limit.) One is now in operation, and two more are planned to go into operation in mid 1992. To place the required cleaning capability in place will require an intensive effort throughout AGMC. Elements of the effort include design and installation of facilities, acquisition of equipment and deionized water systems, and the concurrent development of alternative aqueous processes.

2. In addition to the above actions, a constant stream of related activities will be necessary. These will range from contracted studies to the acquisition of equipment and material. The studies will be necessary to provide information and to find alternatives for difficult-to-resolve solvent uses. The equipment and materials will be necessary to develop and provide both aqueous and other-than-aqueous alternatives to current solvent using processes.

3. Those actions initiated to reduce and eliminate ozone depleting solvent uses will be visibly identified to assure they receive special handling. Hereafter, the paperwork for all such actions will be stamped in red with a large (one-half inch letters) word "OZONE." Any paperwork carrying this stamp is to be treated with urgency and will be expedited to the maximum. Any deviations from this direction shall require written permission from the Commander of AGMC. The "OZONE" stamp will be controlled by the chief of the Office of Environmental Management.

4. Inherent in AGMC's policy are certain factors and assumptions. Those factors within the scope of AGMC's control will be aggressively managed by AGMC to assure positive and timely action. Those assumptions outside AGMC's control such as certain funding, authorization for process change, etc., will be given strong attention at the appropriate level to influence positive results to the maximum degree possible.

Aqueous Cleaning
for
Precision Bearings and Beryllium

by

Don E. Hunt
Gene W. Ott
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Commercial Phone: (614) 522-7220
DSN: 346-7220

November 26, 1991

19960520 016

AQUEOUS CLEANING
FOR
PRECISION BEARINGS AND BERYLLIUM

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ABSTRACT

The Aerospace Guidance and Metrology Center located at Newark Air Force Base in the state of Ohio, U.S.A., repairs inertial navigation and guidance equipment for the United States Air Force. The Center repairs thousands of the delicate, sophisticated electromechanical devices each year. The critical tolerances of many of the moving parts and other considerations mandate extensive "precision" cleaning as well as general cleaning during the repair process. Among the parts requiring cleaning are precision instrument bearings and assemblies containing beryllium. The principal solvents used for this cleaning have been 1,1,2-Trichloro 1,2,2-trifluoroethane (CFC-113) and 1,1,1-Trichloroethane (MCF). The Center has begun modifying its many cleaning processes to use known alternatives for these solvents. Principal among these alternatives are aqueous processes using biodegradable detergents and deionized water. All of the Center's precision instrument bearing cleaning is now done with an aqueous process. Considerable testing and evaluation are nearing completion which indicate that aqueous processes will be used to precision clean beryllium parts with many improvements over the solvent based methods.

INTRODUCTION

The Aerospace Guidance and Metrology Center is located in the state of Ohio, U.S.A., at the Newark Air Force Base. It is a repair center in the U.S. Air Force Logistics Command.

The Center has two primary missions. The first is the repair of inertial guidance and navigation systems and components used by most missiles and aircraft in the U.S. Air Force inventory. The inertial systems and components of several foreign countries are also repaired at the Center. The second mission is the management of the U.S. Air Force Single Integrated Metrology and Calibration Program worldwide.

The Center is comprised of, for the most part, one large building covering approximately fifteen acres. Within this building are a large number of smaller structures totalling over 294,000 square feet of floor space. These structures have strictly controlled environments and contain a vast array of complex repair operations.

The sophisticated electromechanical devices that form the nucleus of inertial systems are extremely susceptible to minute contamination. Particles five microns or less in size can cause a system to fail. As a result, great care must be taken to assure a clean repair environment. Of course, during the repair process it is necessary to carefully clean the parts being assembled.

The Center's industrial processes require extensive use of solvents to meet these cleaning needs and for other specific purposes. Among the solvents used are CFC-113, and 1,1,1-Trichloroethane (MCF). Prior to 1989, the Center used over 1.5 million pounds of CFC-113 annually; less than five hundred thousand pounds was used in 1990

Once used, CFC-113, like many of the solvents, is considered a hazardous waste. The Center reprocesses most of the CFC-113 it uses to virgin quality through a sophisticated distillation system, but a significant portion is lost through evaporation and hazardous waste disposal.

CFC-113, in addition to being a hazardous waste, is a serious threat to the atmosphere. Its impact on the ozone layer has generated action to curb its production and use worldwide.

CFC-113 now costs the Center \$2.40 per pound (\$31.44 per gallon). This is 400% of the cost just two years ago (\$0.60 per pound). In addition, the cost of recovery of vapors from the Center's industrial processes, the cost of hazardous waste disposal, and the cost of reprocessing used CFC-113 contribute to the total cost of its use. The cost of using CFC-113, the threat of even higher cost resulting from special taxes and reduced availability in the future, and environmental issues have caused the Center to take an aggressive role in finding alternatives for this and other hazardous solvents.

For the past three years, Center personnel have been engaged in an intensive evaluation of equipment, techniques, and processes to identify suitable alternatives for a variety of solvent uses.

The Center's repair processes, as mentioned above, require extensive cleaning. The overwhelming majority of the CFC-113 and MCF used at the Center is used in these cleaning activities. The solvents are used in a wide variety of different types of cleaning operations. These can be summarized as flushing, bench, vapor degreasing,

ultrasonic, and impingement spray booth operations. Flushing operations involve the flowing of solvent through the assembly or system being cleaned for a defined period of time. Bench operations encompass all manual cleaning activities accomplished by a repair technician at a work station using solvent for spot cleaning.

The Center has done extensive work testing aqueous processes as alternatives for ozone depleting solvents in the critical, or precision, cleaning of metal parts and assemblies of various compositions. The term "precision" cleaning, as used at the Center, encompasses the removal of particles 10 microns or less in diameter, the preparation of surfaces for ensuing processes where the quality of the ensuing process is dependent on the cleanliness of the surface, where wear between moving parts is a concern, and other special concerns involving "cleanliness".

This work has proven beyond any doubt that aqueous processes are, indeed, suitable for precision cleaning of parts and assemblies consisting of metals, epoxies, plastics, and other materials.

THE CENTER'S AQUEOUS PROCESSES AND PARAMETERS

Many lessons were learned as a result of the thoroughness required to verify that the aqueous processes were suitable as substitutes for ozone depleting solvent based processes and, subsequently, "proving" to management that this was the case. These lessons have caused the Center to not only consider the use of aqueous processes as its principal alternative for ozone depleting solvents, but also to change the basic philosophy of cleaning in its operations.

Prior to the aqueous process investigation, each technician at the Center did his own cleaning for the parts he was working with in the area where he was doing the work. This included all precision cleaning as well as all non-precision, or general, cleaning. Over many years with hundreds of technicians performing their own cleaning, as many different cleaning "techniques" developed as there were technicians. Such a situation is extremely difficult to control for consistency and uniform quality.

Precision cleaning using aqueous processes is being done in a Precision Cleaning Center. The Cleaning Center concept provides several positive improvements to the repair operations. Of course, since fewer cleaning locations will be involved, it minimizes the expense involved in providing the equipment and facilities required for converting to aqueous based precision cleaning. It was learned early in the Center's efforts that the aqueous process worked extremely well for precision cleaning, but only if the various elements in the entire process were closely controlled; the Cleaning Center concept makes this much easier to monitor. Also significant

is the fact that a smaller number of people will be doing the cleaning. This permits a significantly higher degree of quality control in the operation; the cleaning is uniform and consistent. Long term benefits in the reliability of the repaired items are expected to result from this change in concept.

One Precision Cleaning Center has been put into operation and another is planned to go into operation in early 1992. Others will follow. The Cleaning Center concept is still evolving and improvements are being added as they are developed.

The present Cleaning Center is situated in an environment that is maintained to better than a Class 10,000 Clean Room particle count. (A Class 10,000 Clean Room is defined as having less than 10,000 particles which are 0.5 microns in diameter or larger per cubic foot.)

The flooring is an elevated platform composed of two foot square panels that are static electricity dissipative. The technicians wear static electricity dissipative shoes which are put on when entering the Cleaning Center and removed when leaving it. To qualify as static electricity dissipative, the floor and the shoes must have a resistance to ground in the range of 1 to 1,000 megohms. The combination of static dissipative flooring and shoes reduces the incidence of electrostatic charges on the technicians, and, as a result, the effect of electrostatic fields is reduced as a mechanism for recontaminating the parts which have been cleaned.

The Cleaning Center is supplied with deionized water for all of its cleaning operations. The deionized water is maintained to a minimum resistivity of 15 megohms. The quality of the water is critical to the process. The Center's research found that when the water fell below 10 megohms resistivity, the parts being cleaned showed signs of corrosion, stains, and tarnish. These problems were not exhibited when the water resistivity was above 10 megohms.

A low volume, rapid recovery hot water system heats the deionized water to 155 plus or minus 5 degrees Fahrenheit for use in the Cleaning Center. The water is filtered through 0.2 micron absolute filters before use.

The principal cleaning device in the Cleaning Center is a self contained cleaning system that cleans with ultrasonic energy using biodegradable detergents and water in a cylindrical cleaning chamber. The ultrasonic cleaning action is produced via cavitation by a cylindrical space-laminated magnetostrictive nickel design transducer which forms the cleaning chamber. The ultrasonic cleaner operates nominally at a frequency of 20 kHz with a uniform power intensity of 400 watts per gallon. The cylindrical cleaning chamber is 10 inches in diameter and 14 inches deep. Adjustable timers

control wash and rinse cycles. A solution of pure water and detergent from one of two holding tanks is pumped into the cleaning chamber to begin the wash cycle. The solutions in the two holding tanks are continuously filtered through 0.5 micron absolute filters and are maintained according to the detergent used at temperatures that range between 150 and 165 degrees Fahrenheit. When the wash cycle is complete, the detergent and water are drained back to the holding tank. The detergent solutions are reused until the solutions reach an unacceptable level of non-particulate contamination as defined by the Center's Physical Sciences Laboratory. Deionized water is passed over the parts during the rinse cycle to flush away detergent and loosened particles. The ultrasonic action continues during the rinse cycle. The rinse water is discharged to the waste water system as it is used. (Two sources for ultrasonic cleaning equipment with these characteristics are MagnaSonic Systems, Inc., Xenia, Ohio, U.S.A., and Friess Equipment, Inc., Akron, Ohio, U.S.A.)

An aqueous spray booth is also located in the Cleaning Center. It contains a reservoir of heated water and detergent solution. When used, the solution is passed through a 0.2 micron filter. After use, the solution is returned to the reservoir for reuse. The spray pressure is variable between 0 and 200 psig, but pressures in the range of 40 to 60 psig have proven adequate for processes evaluated to date. After spraying with the solution of water and detergent, the technician rinses with heated deionized water. The spray booth with specially designed nozzles permits precleaning of recessed screw holes and other irregularities in a part's geometry prior to final cleaning in the ultrasonic cleaning equipment.

The parts are removed from the cleaner and are placed in a Class 100 laminar flow booth. (Air through a Class 100 laminar flow booth has less than 100 particles 0.5 microns in diameter or larger per cubic foot.) In the laminar flow booth, the parts are blown dry with dry, heated nitrogen. The nitrogen is filtered through a 0.2 micron filter and passed through a nuclear ionizing element to neutralize any electrostatic charge in the nitrogen or on the surfaces it comes in contact with. The parts are then transferred to a vacuum oven where they are completely dried. The vacuum oven is operated at a nominal 160 degrees Fahrenheit and a vacuum of 25 plus or minus 5 inches of mercury. The drying time varies from one to three hours dependent upon the construction and geometry of the parts being dried. After drying, the parts are placed in a second Class 100 laminar flow booth where they are prepared for shipment to their next point of use.

The Center has conducted testing and evaluation of various parts and assemblies consisting of a broad range of materials including copper, beryllium, jewels, various epoxies and plastics, and alloys of iron and aluminum. The Center's evaluation of the aqueous process using the ultrasonic cleaner has demonstrated conclusively on the parts and

assemblies tested to date that with the proper quality of deionized rinse water, proper water temperature, proper filtering of rinse water and detergent solutions, proper timing of wash and rinse cycles, proper selection of detergent, and proper orientation and loading of parts in the ultrasonic cleaning chamber, no degradation, either chemical or metallurgical, results in either the near or long term.

Several ozone depleting solvent based cleaning processes for gyroscopes have been successfully changed to aqueous cleaning at the Center. The gyroscope parts cleaned with the aqueous process include gimbal rings, float shell halves, fill tubes, end bell covers, and gaskets. In addition, miniature precision instrument bearing assemblies from most of the inertial guidance and navigation systems repaired at the Center are now cleaned using the aqueous process.

PRECISION INSTRUMENT BEARINGS

The Center cleans as many as 1000 precision instrument bearing assemblies each month. All these assemblies are cleaned by a completely aqueous process and have been since late 1989. The bearings are cleaned either because contamination in the bearing is suspected to have caused the instrument in which it was installed to malfunction or because they were removed from an instrument during disassembly and must be cleaned to assure they do not contain any contamination generated during the disassembly process. The cleaning of the bearings is part of a refurbishment process to restore those bearings which are deemed to be physically serviceable to a condition where they can meet the necessary specifications for the particular bearing in question. A list of the bearings cleaned at the Center and their materials and physical characteristics are included in Appendix A to this paper.

Prior to cleaning, the bearings are screened by a technician. Those which have defects or other aspects which the technician deems to be undesirable or uncorrectable in the cleaning and relubrication process are discarded. The bearings which pass this initial screening are then prepared for cleaning. The dust covers, if any, are removed and cleaned separately. No retainers are removed, and the balls are not separated from the races for the cleaning process.

The bearings are placed upon a fixture "tree" that orients the bearings such that their axis of rotation is parallel to the sonics of the ultrasonic cleaner. The fixture containing the bearings is then placed in the cylindrical chamber of the ultrasonic cleaner.

The bearings are washed ultrasonically for ten minutes in a detergent solution. The principle detergent used at the Center for this purpose is Ultrakleen 1025 procured from MagnaSonic Systems, Inc.

Other detergents have been tested and work effectively in the process. Following the wash cycle, the bearings are rinsed ultrasonically for five minutes in high quality deionized water.

After rinsing, the fixture containing the bearings is carefully removed from the ultrasonic cleaner and placed in a Class 100 laminar flow booth where the bearings are blown dry with nitrogen. During the nitrogen drying process the technician is careful not to cause the bearings to spin.

After blow drying with nitrogen, the bearings are placed in clean petri dishes. The petri dishes are then placed in a vacuum oven for approximately two hours to thoroughly dry the bearings.

Following removal from the vacuum oven, the bearings are examined under a ten power microscope for defects and contamination. Following this examination, those bearings which pass are subjected to a lubrication process and a final testing process.

When the aqueous cleaning process was first considered as an alternative to the various solvents used to clean the precision instrument bearing assemblies, there were concerns. They included the following. Would corrosion of the bearings increase? Would any damage be caused by the cleaning process and the ultrasonic action? Would the cleanliness that could be obtained equal or exceed that which was obtained by the solvent based process? Testing was conducted to evaluate these concerns.

During the testing phase, various size bearing assemblies cleaned in the aqueous process were disassembled so that their metal parts could be examined and analyzed on a scanning electron microscope (SEM) built by Applied Research Lab. The bearings were checked for residue and any damage done during the cleaning process. All parts that were examined with the SEM showed no residue left (sodium or phosphate) and evidenced no damage done during the cleaning process. Teflon inserts were examined for expansion or shrinkage due to heat. No changes in dimensions were detected.

As a final test for the bearings cleaned with the aqueous process and then refurbished, a trace for each bearing was obtained on a running torque tester to test for bearing serviceability. The tester used for this purpose is a Model RT2C Bearing Torque Tester made by Miniature Precision Bearings Corporation. The bearings were rotated both directions on the tester. The magnitude and pattern of the peaks on the RT2C Tester indicate various conditions in the bearing such as poor geometry, possible retainer hangup, dirt spikes/contaminated bearing, a brinell or flat on a raceway, brinelled or potted raceway, and poor race to face parallelism within the bearing geometry. This testing indicated that the bearings cleaned with the aqueous process were not being damaged during the

ultrasonic cleaning process and that no measurable contamination remained after the cleaning. The results of the various testing satisfied the Center's personnel that the aqueous process was, indeed, an acceptable alternative to the solvent based processes.

Following implementation of the aqueous cleaning process for precision instrument bearings, the Center's technicians have observed less formation of surface corrosion than they had observed with the previous processes. Our Physical Sciences Laboratory personnel have deduced the reason for less formation of corrosion following the aqueous cleaning is that the bearings are now being cleaned more thoroughly and that fewer contaminants remain on the bearing surface to cause corrosion.

Many benefits resulted from the implementation of the aqueous cleaning process for precision instrument bearings. These benefits include reduced solvent consumption, reduced cleaning process time, improved cleanliness, reduced corrosion, reduced cost for cleaning medium, and higher yields. Yields of all the bearings passing through the refurbishment process have increased; the yield increases have ranged from 25% to 65%.

BERYLLIUM

The metal beryllium has been used extensively in inertial systems and components because of its lightness and high strength-to-weight ratio, stiffness and good machinability. Several of the systems and components repaired at the Center have beryllium components. These include aircraft as well as missile navigation and guidance systems. There is a common belief, however, in many circles that beryllium cannot be cleaned with aqueous processes because of associated corrosion potential.

In 1965 A. J. Stonehouse and W. W. Beaver of the Brush Beryllium Company, Cleveland, Ohio, published an article titled "Beryllium Corrosion and how to prevent it" in Volume 4, No. 1, of Materials Protection, an official publication of the National Association of Corrosion Engineers. In their article they state "In low temperature, high purity water, there is little or no corrosion problem with beryllium." They identify "low temperature water" as being below 210 degrees Fahrenheit. They further describe testing they had done on "unprotected beryllium" using water and detergent as a cleaning medium: "Cleaning followed by adequate rinsing and drying will increase the metal's resistance to corrosion." Stonehouse and Beaver are also quick to point out "...beryllium's performance in tap water is poor..." citing that small concentrations of several ions including ions of chloride and sulfate will cause pitting and other evidences of corrosion.

In 1990, with this information as a starting point, the Center's engineers began testing the high purity aqueous cleaning processes they had developed on beryllium. The results of this testing have been exciting. Beryllium components from two major systems have been extensively tested and aqueous processes have been developed which perform splendidly.

As has been the case in all the aqueous processes developed at the Center, the processes developed to clean beryllium required tailoring. Fixturing was made to align some parts in a particular orientation in the ultrasonic field of the cleaner. The detergent found to be effective at removing the contaminants of the parts tested to date with the least effect on the beryllium itself is Liquid Detergent Number 2 manufactured by Oakite Products, Inc., Berkeley Heights, New Jersey. This detergent is used in many of the Center's aqueous processes.

An interesting illustration of the tailoring required to adapt aqueous processes to the particular cleaning requirement at hand occurred with the beryllium end housing of a component used in the Minuteman missile guidance system. The end housing had small diameter, dead end, threaded holes around its circumference. The old process for cleaning the end housing with solvents required many iterations of the cleaning steps to remove all traces of oil from these particular holes. It was found that the same thing occurred with the aqueous process when it was first tried, i.e. the ultrasonic cleaning system did not adequately clean the inside of the holes. The engineers then made a small nozzle to fit inside the hole; the nozzle was attached to an aqueous spray system in a booth where the technician can quickly use water and detergent to clean each hole manually and, using the same nozzle, rinse with heated deionized water. Following the spray operation, the end housing is final cleaned in the ultrasonic cleaner. Significantly fewer ultrasonic cycles are required to attain the same level of contamination removal as the current process.

The beryllium assemblies tested to date include, in addition to beryllium, stainless steel, gold, an epoxy resin potting compound, aluminum oxide, etc. With these assemblies and with pure beryllium parts, the results of the aqueous processes are excellent. The parts and assemblies can be cleaned cleaner than they were cleaned using solvents. They can be cleaned faster and, most importantly, they can be cleaned without any chemical or metallurgical damage. No corrosion results, and integral aspects of assemblies such as epoxy seals are not damaged.

The testing and evaluation of aqueous cleaning for beryllium parts and assemblies is nearing completion at the Center. Converting the present solvent based cleaning processes for beryllium to aqueous

processes is expected to take place in early 1992 for certain Minuteman missile guidance system components and for parts of the Carousel inertial navigation system.

CONCLUSION

Despite commonly encountered rhetoric to the contrary, precision bearings and beryllium can be effectively cleaned with aqueous processes; the Aerospace Guidance and Metrology Center is doing it and obtaining very gratifying results. With proper attention to process parameters developed through careful testing and evaluation, the Center has concluded it can clean precision bearings and beryllium with aqueous processes with no corrosion from the process or subsequent to it if the items in question are handled and stored properly. Also, faster cleaning times and better cleaning are achieved over the traditional solvent based methods.

APPENDIX A

Precision Bearings Cleaned at AGMC

The precision instrument bearings identified in this document are routinely cleaned by the Aerospace Guidance & Metrology Center (AGMC) at Newark Air Force Base in Ohio, USA as part of a refurbishment process for the bearings. The cleaning process is an aqueous process using an ultrasonic cleaner, detergent, and deionized water. All bearings are ball bearings used in various capacities in inertial guidance and navigation systems repaired at AGMC. The bearing information included was obtained from manufacturer data sheets or from the Air Force Master Item Identification Database (D043A) located at Wright Patterson AFB, Ohio.

A list of definitions for the abbreviations and terminology used is included below.

Definitions

430 SST	- Type 430 Stainless Steel
440C SST	- Type 440C Stainless Steel
960446	- Litton specification (oil)
AISI	- American Iron & Steel Institute
Cres	- Corrosion Resistant Steel
Dia	- diameter (inches)
HC/Cr Steel	- High Carbon Chromium Steel
IAW	- in accordance with
MIL-L-####	- Military Specification Number
NSN	- National Stock Number
QQ-S-####	- Federal Specification/Standard
Ret	- Retainers
SAE	- Society of Automotive Engineers
SAE 52100	- AISI E52100 (Chrome Steel)
Sep	- Separators
SM####	- Specification Number
SST	- Stainless Steel

Note: Items with Asterisks (*) are tested on a Miniature Precision Bearings (MPB) Torque Tester (Model RT-2) after cleaning and lubrication to verify the bearings meet the required specifications.

Bearing 1:	MATERIALS	Rings - SAE 52100 Balls - SAE 52100 Retainer - Phenolic
	LUBRICANT	Mobil 28
	OUTER DIA.	.5000-.0002
	INNER DIA.	.1573-.0002
Bearing 2: *	MATERIALS	Rings - SAE 52100 Balls - SAE 52100
	LUBRICANT	MIL-L-6085A
	OUTER DIA.	.5000-.0002
	INNER DIA.	.1875-.0002
Bearing 3:	MATERIALS	Rings - SAE 52100 Balls - SAE 52100 Retainer - Phenolic (paper-based)
	LUBRICANT	Mobil 28
	OUTER DIA.	.6299/.6297
	INNER DIA.	.1575/.1573
Bearing 4:	MATERIALS	Steel Corrosion Resisting Overall
	LUBRICANT	MIL-L-6085
	OUTER DIA.	.5 nominal
	INNER DIA.	.25 nominal
Bearing 5: *	MATERIALS	Rings, Balls, Ret - Steel Shields - Steel Corrosion Resisting
	LUBRICANT	MIL-L-6085
	OUTER DIA.	.375 nominal
	INNER DIA.	.125 nominal
Bearing 6: *	MATERIALS	Rings - HC/Cr STL Balls - HC/Cr STL Separator (in) - SST (out) - Teflon
	LUBRICANT	SM2049-01
	OUTER DIA.	.6248/.6250
	INNER DIA.	.1873/.1875
Bearing 7: *	MATERIALS	Rings, Balls - SST Sep, Shields - SST
	LUBRICANT	SM2049-01 (Mobil 714)
	OUTER DIA.	.5000/.4998
	INNER DIA.	.1875/.1873

Bearing 8: *	MATERIALS	Rings, Balls - SM2058 Sep, Shields, Ret Rings - SST
	LUBRICANT	SM2049-02 (Mobil 743)
	OUTER DIA.	.5000/.4998
	INNER DIA.	.1875/.1873
Bearing 9: *	MATERIALS	Rings, Balls - HC/Cr STL Sep - Teflon
	LUBRICANT	Shields, Ret Rings - SST SM2049-01
Bearing 10:	MATERIALS	Rings, Balls - 440C SST Ret - 430 SST
	LUBRICANT	Anderol L243 (SM1560)
	OUTER DIA.	.8750/.8748
	INNER DIA.	.4100/.4098
Bearing 11: *	MATERIALS	Rings, Balls - SAE 52100 Shields, Ret - Cres per QQ-S-763, series 300 or 400
	LUBRICANT	Mobil 743A
	OUTER DIA.	.6250-.0002
	INNER DIA.	.2500-.0002
Bearing 12: *	MATERIALS	Rings, Balls - SAE 52100 Retainer - Cres (type 430) Sep - Teflon
	LUBRICANT	Shields - Cres per QQ-S-763/766, class 302 Mobil 743
	OUTER DIA.	.6250-.0002
	INNER DIA.	.18745-.00005
Bearing 13: *	MATERIALS	Rings, Balls - SM2058 Sep (in) - SST (out) - Teflon
	LUBRICANT	Shields, Ret - 302 SST SM2049-01
	OUTER DIA.	.6250/.6248
	INNER DIA.	.1875/.1873
Bearing 14: *	MATERIALS	Steel Corrosion Resisting Overall
	LUBRICANT	MIL-L-6085
	OUTER DIA.	.5 nominal
	INNER DIA.	.1875 nominal
Bearing 15: *	MATERIALS	Rings, Balls, Sep, Shields, Ret - SST
	LUBRICANT	MIL-L-6085 (SM1827)
	OUTER DIA.	.6250/.6248

	INNER DIA.	.2500/.2498
Bearing 16: *	MATERIALS	Cres overall
	LUBRICANT	MIL-L-6085
	OUTER DIA.	.625/.6248
	INNER DIA.	.25/.2498
Bearing 17:	MATERIALS	Rings, Balls - Cres, 440C
		Ret - 24 ST aluminum bonded to phenolic
	LUBRICANT	MIL-L-6085
	OUTER DIA.	1.1875/1.1871
	INNER DIA.	.75/.7497
Bearing 18:	MATERIALS	Cres overall
	OUTER DIA.	.5 nominal
	INNER DIA.	.1875 nominal
Bearing 19:	MATERIALS	Steel, comp 440A overall
	LUBRICANT	Grease
	OUTER DIA.	.375/.3748
	INNER DIA.	.1295/.1293
Bearing 20:	MATERIALS	Rings, Balls - Cres, 440C
		Spacer - Cres springs
		Ret - Teflon
	LUBRICANT	IAW 960446
	OUTER DIA.	3.125/3.1245
	INNER DIA.	2.5625/2.5621
Bearing 21:	MATERIALS	Rings, Balls - Cres, 440C
		Sep - Teflon
	LUBRICANT	IAW 960446
	OUTER DIA.	.5/.4998
	INNER DIA.	.25/.2498
Bearing 22:	MATERIALS	Rings, Balls - Cres, 440C
		Sep - Teflon
	LUBRICANT	IAW 960446
	OUTER DIA.	1.3125/1.3121
	INNER DIA.	1.0625/1.0623
Bearing 23:	MATERIALS	Rings, Ball - Steel comp 440C
		Ret - Plastic tetraflouroethylene
	OUTER DIA.	4.5 nominal
	INNER DIA.	4.0 nominal
Bearing 24:	MATERIALS	Rings, Ball - Steel comp 440A
		Ret - Plastic Polytetraflouroethylene
	OUTER DIA.	2.2497/2.2494

Bearing 25:	INNER DIA.	1.8122/1.8119
	MATERIALS	Rings, Ball - Steel, comp 440A
		Ret - Plastic Polytetraflouroethylene
	OUTER DIA.	2.25/2.2496
	INNER DIA.	1.8125/1.8121
Bearing 26:	MATERIALS	Rings, Balls - Steel comp 440A
	OUTER DIA.	2.2498 nominal
	INNER DIA.	1.8123/1.8119
Bearing 27:	MATERIALS	Rings, Ball - Steel Comp 52100
		Ret - Plastic Polytetraflouroethylene
	LUBRICANT	MIL-L-6085
	OUTER DIA.	4.0/3.9997
	INNER DIA.	3.5/3.49975
Bearing 28:	MATERIALS	Rings, Ball - 52100 Steel
	OUTER DIA.	.5 nominal
	INNER DIA.	.1565-.0005
Bearing 29:	MATERIALS	Rings - 52100 Steel
	OUTER DIA.	.5 nominal
	INNER DIA.	.1562/.1560